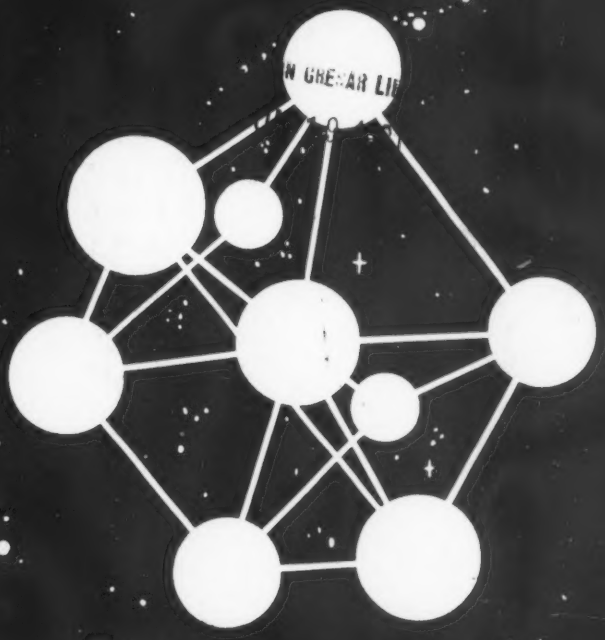
NUCLEAR ENERGY

THE JOURNAL OF THE INSTITUTION OF NUCLEAR ENGINEERS



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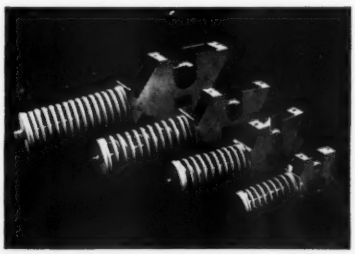

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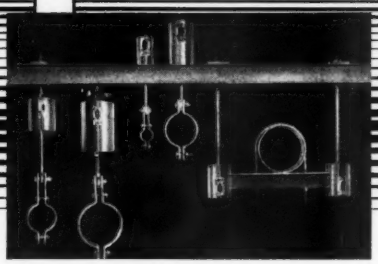

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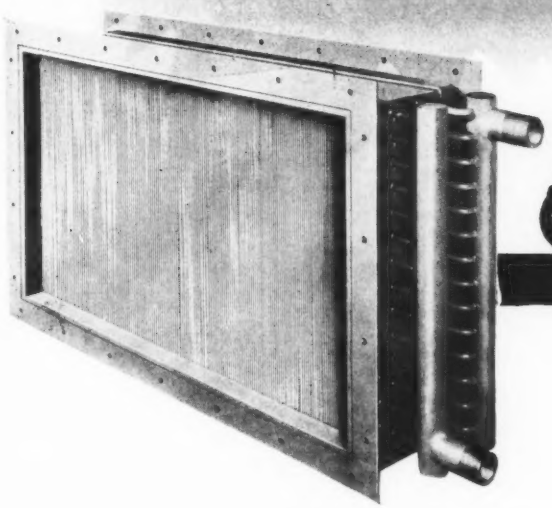

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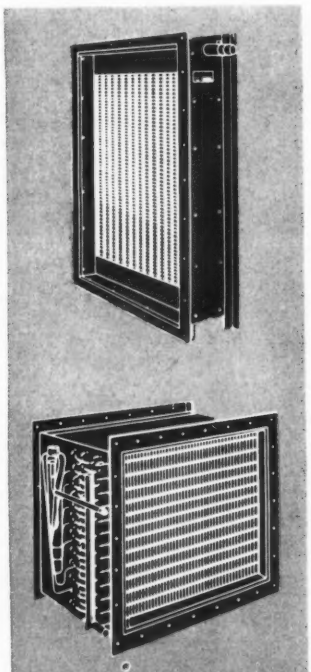

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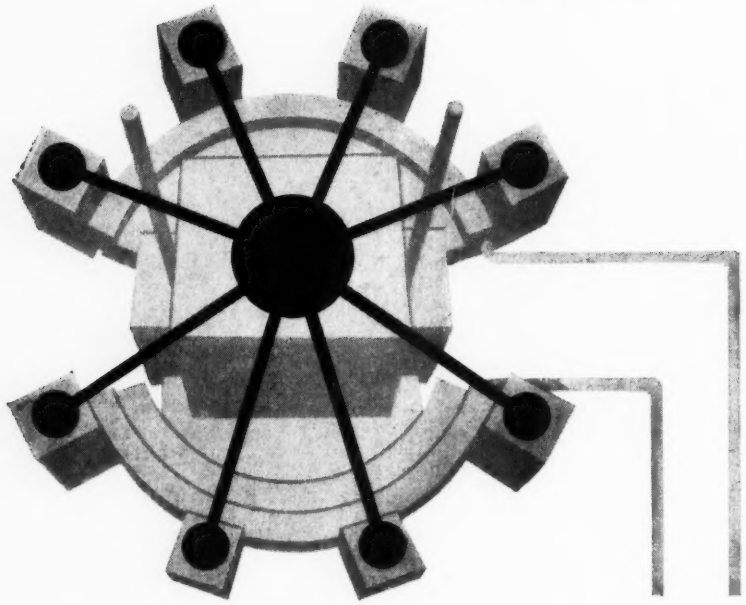
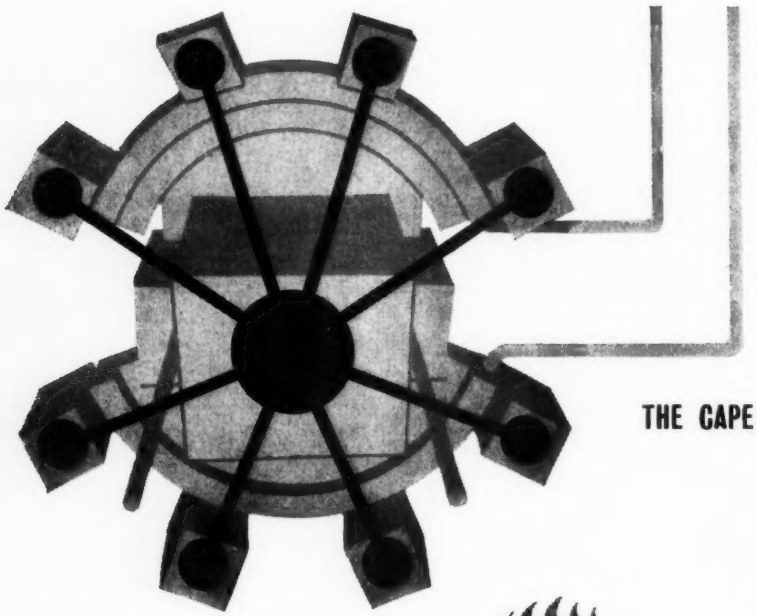


BERKELEY—a challenge to insulation



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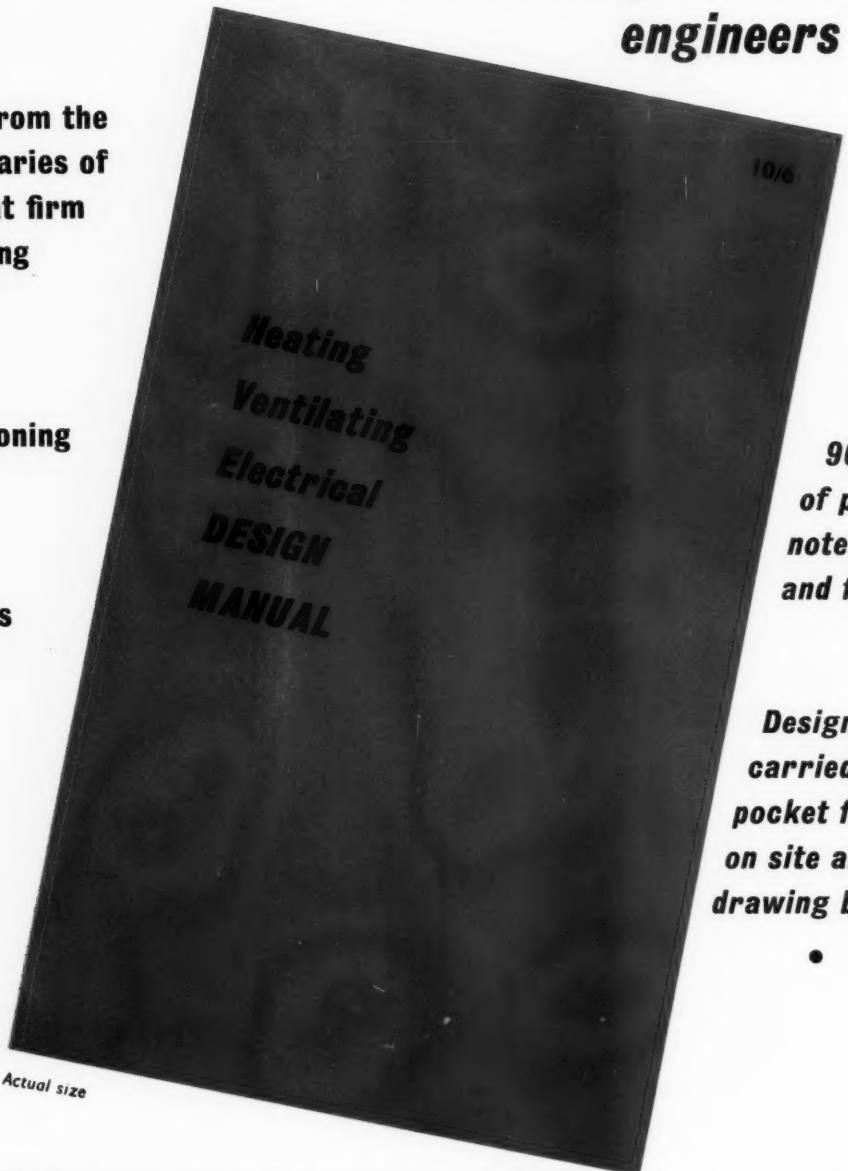

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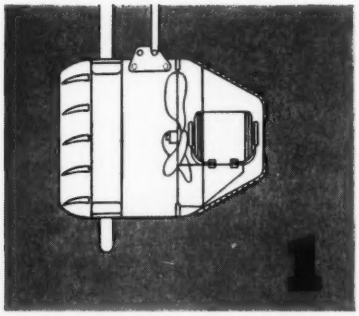

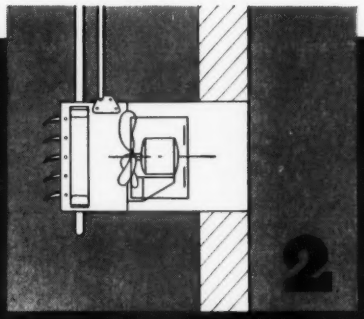

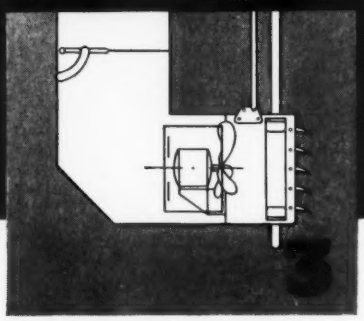

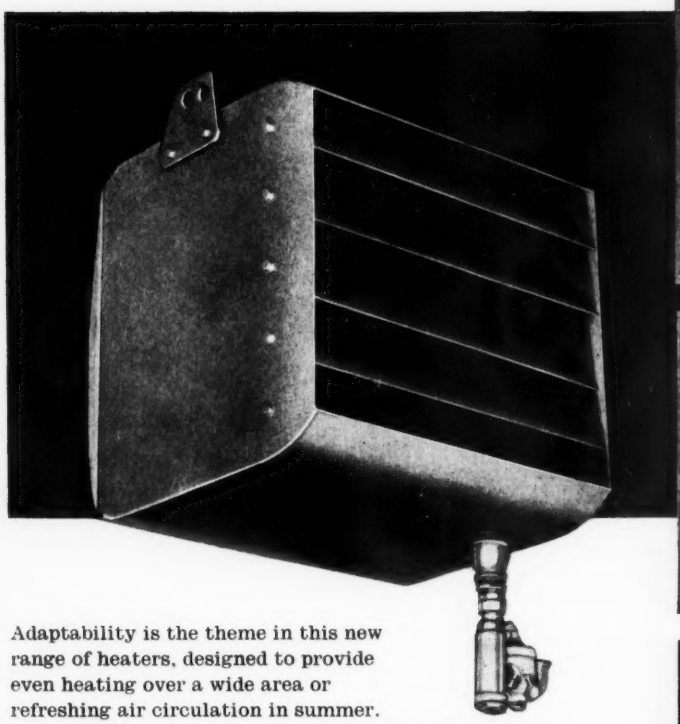

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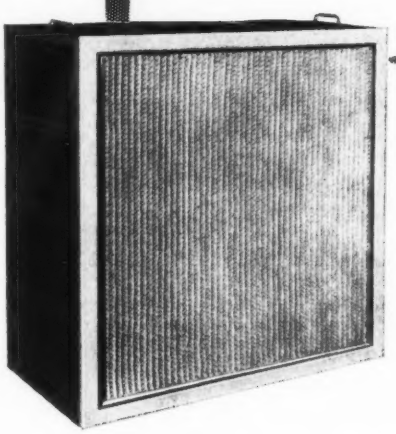

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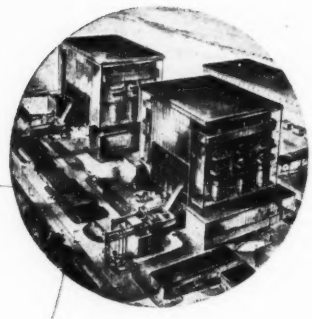

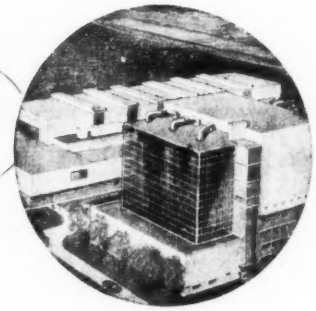

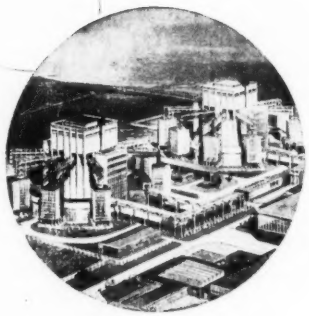

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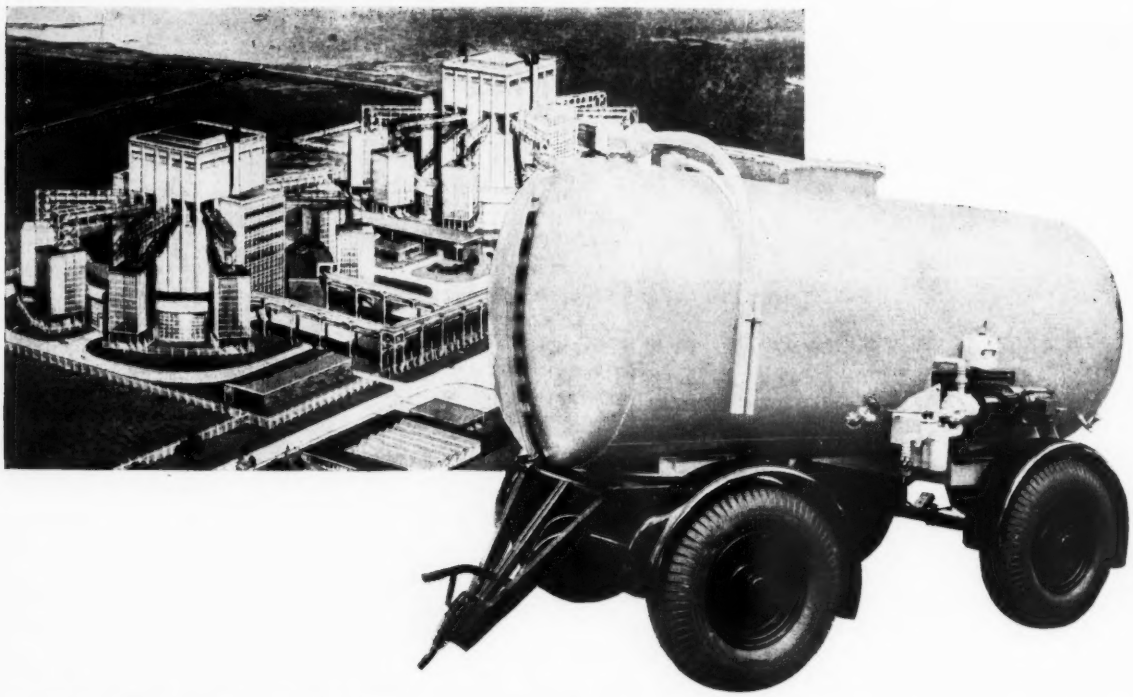

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The 1,000 gallon tank illustrated above is one of a pair supplied with a 250 g.p.h. Stream-Line insulating oil filter to the British Thomson-Houston Co. Ltd., for use at Berkeley Power Station. Larger capacity tanks are also available, including models which combine clean and dirty tanks on a single transporter.

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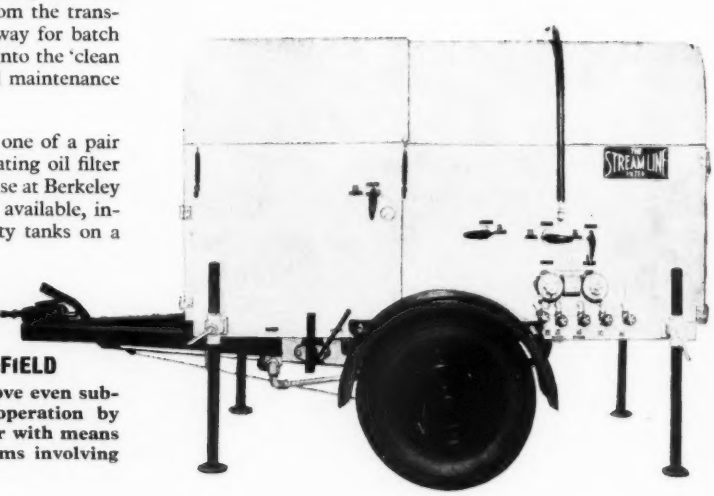

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Pinkerton Founder Award

AS announced in the March issue of NUCLEAR ENERGY, the Pinkerton Founder Award for 1960 has been divided between two authors, each receiving 50 guineas. The Award-winning papers have now been read to the Institution, and one of them, "Electric Power from Nuclear Heat—Direct," by J. W. Gardner is published in this issue. Unfortunately, the other paper, "Siting of Nuclear Power Reactors in the U.K." by A. Quinton cannot be published until clearance is received from the UKAEA. It is hoped that this clearance will be forthcoming in the near future.

The first two photos on this page were taken at the Institution meeting on May 2nd, when Mr. Quinton presented a modified version of his paper. Mr. Quinton was born in 1914 and received his university education at King's College, London. From 1947-57 he was Chief Hospital Physicist at Queen Elizabeth Hospital, Birmingham. At present Mr. Quinton is Senior Health Physicist of the Safeguards Division at Risley; he has had various papers published on the peaceful uses of radio-isotopes and radiation effects on materials.

(*Above*) **Mr. Quinton presenting his paper on May 2nd; in the centre is the chairman, Mr. D. S. Watt, and right, Mr. F. L. Coombs**

(*Below*) **A section of the audience at the meeting on May 2nd**

Meeting on May 9th

The Award-winning paper by Dr. Gardner was presented to a meeting of the Institution at Caxton Hall on May 9th. Dr. Gardner was unable to be present so the paper was read by Dr. Grassam. A lively discussion followed the presentation of the paper; this will appear in NUCLEAR ENERGY in due course. Written contributions to this discussion should be sent to the Secretary of the Institution.

Admiral Giben (*right*) talking to Captain Grindlewood at the meeting on May 9th

Dr. Grassam (*right*) and A. Wyatt before the start of the meeting

Two members of the audience, C. J. Hurd (*left*) and J. H. King

Shell achievement

One of Shell's recent achievements in Industrial Lubrication has been to reduce the risk of skin trouble for machine operators. Until the new Shell Dromus range, most modern soluble cutting oils contained phenolic compounds, which can cause skin irritation. They were used as coupling agents between the actual oil and the emulsifier. On high-speed machines, especially, the water evaporates and the emulsion concentrates. And that's when the trouble can start. Shell scientists found a better coupling agent, and made it work. And now, at no extra cost, management can reduce working risks for their staff. *Write for the book, 'Selecting Your Cutting Oils', to Shell-Mex House, London, W.C.2.*

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(*Right*) **Dr. Grassam reading the paper by Dr. Gardner**

(*Below*) **M. Kusmirak (*left*) and H. J. Ife**

Electric Power from Nuclear Heat—Direct

by J. W. Gardner, BSc, PhD, MINucE*

The direct conversion of the heat of nuclear fission into electric power, without the intermediary of turbines or other moving parts, has already been demonstrated on the laboratory scale. Before this technique can be exploited for large-scale use in nuclear power stations, however, much fundamental work needs to be done on the behaviour of thermoelectric and thermionic materials under intense nuclear irradiation at high temperature. Not least of the difficulties besetting such a programme is the acute shortage of high calibre scientists and engineers trained in this novel and specialized field.

Introduction

IT has been said[1] that nuclear reactor technology is unique in having sprung up full blown almost overnight. An interval of merely four years separated the discovery of fission (1938) and the first chain reaction (1942). The first moderately powered reactor went critical at Oak Ridge in 1943; electricity was first produced from fission in the Experimental Breeder Reactor I, in Idaho in 1951; in 1956 electricity from the UKAEA nuclear power station at Calder Hall was first fed into the national grid: and at the time of writing the first large-scale commercially built nuclear power stations are becoming due for commissioning.

In view of this " forced growth " of the new technology it is remarkable that the nuclear power stations now being built are expected to be only marginally less efficient (thermally and economically) than present conventional power stations; and the more advanced nuclear power stations currently planned are expected to be actually *more* efficient than their conventional counterparts.

A nuclear power generator, no less than a conventional one, is a thermodynamic engine and as such is, of course, subject to the limitation that the thermal efficiency cannot exceed $(T_1-T_2)/T_1$, where T_1 and T_2 are respectively the Carnot cycle heat source and sink temperatures in degrees absolute. In fact in both types of generator as currently designed the conversion of heat to electric power is done (necessarily) in such a roundabout way that the practical efficiency falls well below that theoretically attainable. Both nuclear and conventional power stations—and indeed most of our present-day power units—operate broadly along the following lines: fuel (fossil or nuclear) is burnt and the combustion heat produces gas or

*Atomic Power Division, English Electric Co., Ltd., Whetstone, Leicester.

vapour at high pressure which pushes on a metal surface, producing rotary motion which is then used to run a rotary dynamo. This sequence applies in its entirety to the steam cycle, the gas turbine and the internal combustion engine; its last stages also apply to hydroelectric generation and to proposals for using the power of tides and winds to generate electricity.

Advantages

The potential advantages of eliminating this sequence and producing electricity directly from some form of primary energy (chemical, thermal, nuclear fission, etc.) are great indeed and have long constituted a fascinating challenge to man's scientific ingenuity and imagination. Reduced capital cost, improved reliability and higher efficiency should all result from the replacement of a long and complicated chain of components by a single unit without moving parts. Thus there is a powerful economic incentive for the development of direct conversion generators for commercial and industrial applications; for certain special applications, such as power units for space vehicles, they are virtually indispensable.

Much of the recent interest in and support for work on direct conversion devices undoubtedly stems from these special applications where robustness and compactness are at a great premium, and cost is a secondary consideration. Nevertheless, it is quite evident from recent publications[2–7] that industry, particularly in the U.S.A., is now taking an active interest in the development of units capable of the economic generation of electric power on a commercial scale. The basic concepts which, on present evidence, appear to offer a development potential as ultimate large-scale direct conversion generators are:—

(1) Magnetohydrodynamic conversion (separation of positive and negative charges in a gas);
(2) Fuel cells (separation of positive and negative charges during a chemical reaction);
(3) Thermoelectric conversion (principle of the thermocouple);
(4) Thermionic conversion (principle of the radio diode).

All of these devices could in principle be used in conjunction with a nuclear reactor but the last two appear most suited to this application, and it is on these that we shall concentrate. The basic physical facts about thermoelectric and thermionic conversion will be summarized and the difficulties besetting the construction of practical generators will be outlined. To minimize heat wastage the conversion device should obviously be as close as possible to the nuclear fuel, but at present this advantage is largely offset by radiation damage to the converter materials. Significant progress must therefore await the development of new materials capable of withstanding prolonged irradiation at high temperature.

Such materials are unlikely to be discovered accidentally: the surer approach, though it may take ten years, is to extend our fundamental knowledge of the radiation damage process so that we know what kind of materials to look for, and where to look for them, or how to make them. A few suggestions for such a fundamental research programme are made later.

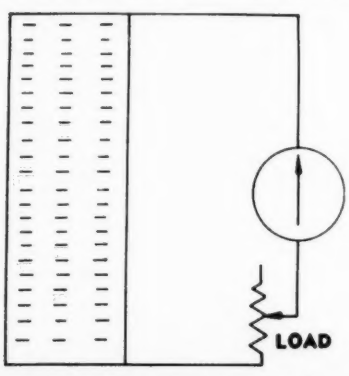

Fig. 1(a).—Thermoelectric generator. In a uniformly heated material the free electrons are uniformly distributed: no current flows around external circuit

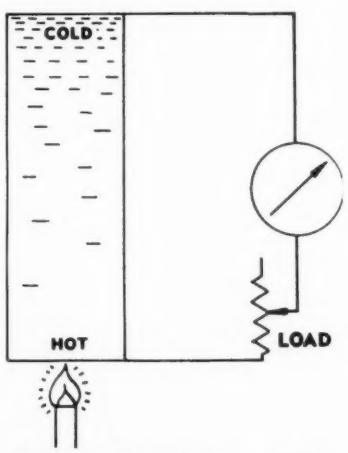

Fig. 1(b).—Thermoelectric generator. Under influence of thermal gradient electrons migrate to cold end of bar and a potential difference is thus available to cause flow of current in an external load circuit

Thermoelectric Fundamentals

In metals and other good conductors electric current is carried by free electrons, unattached to atoms. There are about 10^{23} such electrons in 1 cu.in. of a good metallic conductor, and even when no macroscopic current is flowing they have violent random motions which increase with temperature. If one end of a metal bar is heated the random motions of the electrons at that end will increase, with the result that there will be a net migration of electrons away from the hot end and towards the cold end (*see* Figs. 1(*a*) and 1(*b*)). Such a systematic electronic drift of course constitutes an electric current, which may be legitimately described as being driven through the metal by the heat applied at one end. Here then is a direct conversion device: heat one end of a metal bar and an electric current flows. It sounds all too easy, and it is, as we shall see by considering what happens if we try to draw off the thermoelectric current to do useful external work.

Seebeck Effect

Let us consider the simplest possible external circuit consisting of a loop of wire joining the hot end of the bar to the cold end. (The wire could represent *e.g.* a motor winding, but that need not concern us here.) Now this wire, being a good conductor by definition, will also contain free electrons in about the same concentration as the bar itself. Moreover, since the ends of the wire are in thermal contact with the ends of the bar, the resulting thermal gradient in the wire produces a thermoelectric current which opposes the current we are trying to draw from the bar. Actually, if bar and wire are not made of the same metal the electronic concentration will not be quite the same in each, and a small net current will flow around the circuit. This is the well-known effect discovered by the Berlin experimenter Thomas Johann Seebeck in 1821 and named after him. (Seebeck, who

died in 1831, could not, of course, have realized the true nature of his discovery since the atomic structure of matter and the existence and nature of the electron were not elucidated until the late nineteenth century.)

Evidently the Seebeck effect in metals is not a very efficient way of converting heat to electricity, for the flow of any current at all is dependent on the slight difference in free electron concentration existing between the two metals. Nevertheless, by suitable choice of dissimilar metals and the use of many thermocouples in series (thermopile), efficiencies by 1850 had been raised to 3 per cent., which was higher than the efficiencies of the steam engines of those days. For almost a century after that, although thermocouples were widely used for measuring temperatures, their efficiency as generators could not be improved and it seemed that the limit had been reached.

Semiconductors

This situation has changed significantly in the past decade or so with the discovery and development of "semiconductors," having properties intermediate between conductors and insulators. In a perfect insulator each atom has exactly its full complement of electrons with none to spare; in a metal there is, as we have seen, a considerable excess of free electrons, viz., about 10^{23}/cu.in. Semiconductors are classified into *n*-type and *p*-type: an *n*-type semiconductor contains about 10^{20} free electrons/cu. in., whilst in a *p*-type there is a deficiency of electrons. The vacancies due to these missing electrons behave like free electrons with a positive charge and are usually known as "positive holes." A *p*-type semiconductor contains about 10^{20} such positive holes/cu.in.*

Now we have seen in the above discussion of a thermocouple made of two dissimilar metals that the net current generated is the difference between opposing currents flowing in the two branches. It is easy to see, on the other hand, that in a thermocouple having one branch of *n*-type and the other branch of *p*-type semiconductor the thermoelectric currents in the two branches will reinforce (*see* Fig. 2).

*This picture of semiconductors, although correct in essentials, is over-simplified. For a fuller account the interested reader is referred to such monographs as references 8 and 9.

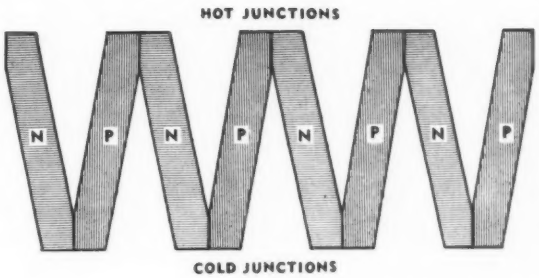

Fig. 2.—Thermopile in which the alternate elements are *n*-type and *p*-type semiconductors

Another advantage of replacing metals by semiconductors in thermocouples stems from the fact that metals are excellent conductors of heat, as well as electricity. This makes it extremely difficult to maintain a large temperature difference between hot and cold junctions and consequently imposes a severe limitation on the thermoelectric e.m.f., which is directly proportional to the temperature difference. Ideally, what is required is something which is both a perfect electrical conductor and a perfect thermal insulator; no such ideal material exists but semiconductors on the whole come much closer to it than metals do.

Nuclear Applications

The design of a practical thermoelectric generator is complicated by the fact that semiconductor properties change with temperature so that for any given material the best compromise of properties will exist for only a small temperature range. On the other hand, as we have seen, a large temperature difference between hot and cold junctions is required to obtain a useful output voltage. The difficulty could in principle be met by constructing a thermopile in which the stages are made of different materials, each efficient in its small temperature region. For temperatures up to about 1,000°F., suitable materials are already available. However, hot-junction temperatures above 2,000°F. would probably be needed to obtain a worthwhile efficiency in any large-scale thermoelectric power generator.

At these higher temperatures semiconductors are no longer suitable since they become "intrinsic"; that is, the input heat causes positive and negative charges to migrate in equal numbers and so no output voltage is obtained. A possible way out of this difficulty would be to use insulators which have been suitably "doped" to become good thermoelectric materials, and which do not become intrinsic until temperatures well above 2,000°F. For example, pure nickel oxide is normally an insulator but if it is modified by the addition of 3 per cent. of lithium its resistivity decreases to about 0.01 ohm/cm. The explanation of this behaviour appears to be as follows: in normal nickel oxide the nickel has a valence of plus two but the addition of lithium causes the appearance of nickel with valence plus one; the exchange of charges between plus-one nickel and plus-two nickel accounts for the vastly increased conductivity. Similar modifications to other insulating materials are currently under active investigation, for example in the Pittsburgh Laboratories of the Westinghouse Corporation[10].

Material Fabrication

Further problems are encountered in the fabrication of these new materials into thermocouples and their subsequent assembly into complete thermopiles. Obviously this must be done in such a way as to minimize the contact resistances between the different materials employed, for high contact resistance would have the same effect as a high internal resistivity of the material, reducing the efficiency. Also, at temperatures above 500-600°F., it is necessary for thermopiles to be shielded from the air to prevent corrosion, and deterioration of the joints.

What has been said up to now applies equally whether the heat source for a thermoelectric generator is a conventional furnace or a nuclear reactor. In the latter case, however, the risk of damage by nuclear radiations is combined with the hazards of high temperatures and chemical attack. Very little is known about the behaviour of thermoelectric materials under conditions

of prolonged and intensive nuclear irradiation such as they would be exposed to in a large power reactor. Westinghouse Laboratories report little change in the thermoelectric properties of the lithium-treated nickel oxide after exposure to total integrated thermal neutron flux of 1.4×10^{19}; but this is equivalent to only about four days' exposure in one of the reactors of the Hinkley Point nuclear power station, whereas a useful life of the order of years would presumably be a prerequisite for any worthwhile thermoelectric generator.

Greater Efficiencies

However, if suitable materials can be found it seems certain that much greater efficiencies in thermoelectric applications will be possible with nuclear rather than conventional heat sources. This is primarily because in a reactor it will be possible to have the heat source, *i.e.*, the nuclear fuel element, completely surrounded by thermoelectric elements and so eliminate stack losses (*see* Fig. 3). There are in fact possible nuclear fuel materials such as uranium and thorium sulphide which are themselves semiconductors, but it is not yet known what the long-term thermoelectric behaviour of these would be in a nuclear reactor. Evidently there is a considerable practical incentive to investigate the properties of thermoelectric materials under prolonged nuclear irradiation.

The idea of using a nuclear reactor as the heat source in a thermoelectric generator is also attractive for the following reason. It has already been indicated that in any practical generator a large number of stages in series will be required since a single thermocouple delivers only fractional voltage; for example, for bismuth telluride—a typical material in this connection—the output is around 10 millivolts for a temperature difference of 100°F. between hot and cold junctions. Now, evidently, the fact that a typical nuclear power reactor contains many thousands of fuel elements could be exploited if thermocouples incorporated in these fuel elements were connected in series to produce reasonably high output voltages. This idea has been developed in more detail elsewhere[6,11].

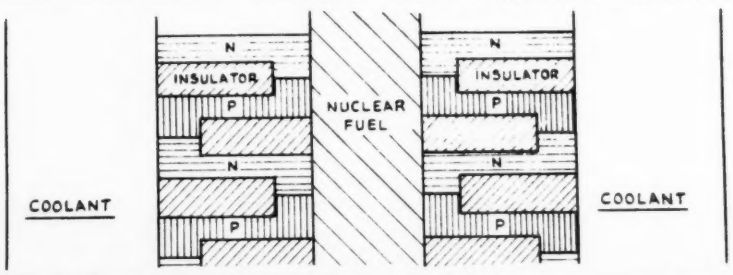

Fig. 3.—Direct type thermoelectric generator: thermoelectric elements are wrapped around nuclear fuel elements and heat from fission is converted directly to electrical energy

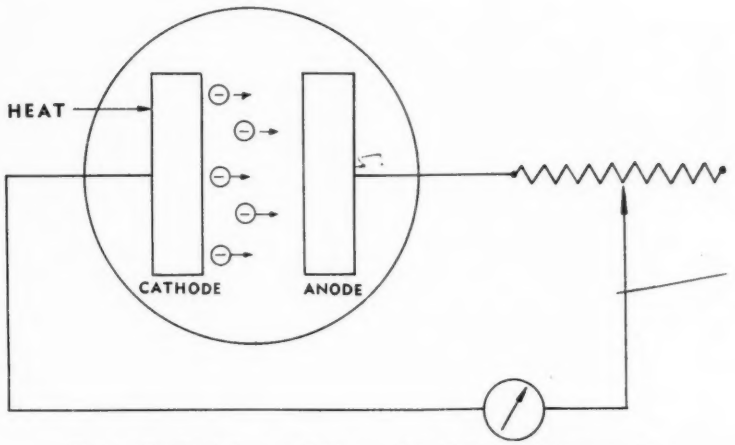

Fig. 4.—Simplified diagram of the operation of the thermionic generator

Laboratory Models

As an indication of the present "state of the art" of thermoelectric generation may be cited the fact that laboratory models in the 1w to 10 kW output range are already being built[6]. These models use indirect (conventional) heating. Although the intrinsic efficiency of conversion of heat to electricity depends only on the thermoelectric properties of the materials used, and is independent of the size of the generator, nevertheless design studies indicate that stack losses and other practical disadvantages will reduce the overall efficiency of indirect type generators above the 10 kW size. For larger outputs it appears therefore that the direct type, where the thermoelectric elements surround or are incorporated in the nuclear fuel, will be superior. The development of these depends, as we have seen, on finding materials which retain their thermoelectric properties under prolonged nuclear irradiation.

With the best present-day materials (unirradiated) the intrinsic efficiency of thermoelectric generation is about 17 per cent., which, however, becomes an overall efficiency of only about 6 per cent. if the heat source is a conventional fuel burner[10]. It has been conjectured[6] that in about five years new materials will have an intrinsic efficiency of about 30 per cent.

Thermionic Converters

The ordinary radio diode valve operates on the oldest principle known in electronics, discovered by Thomas Edison towards the end of the last century. Application of heat to the cathode "boils off" electrons from its surface by imparting to them sufficient energy to enable them to surmount the potential barrier at the surface. The electrons flow to the anode and thence to the external circuit (*see* Fig. 4). The anode must be kept relatively cool to prevent back emission from this surface.

In a typical radio diode the power output could be about a microwatt (say a microampere at a volt) whereas the input power required for cathode heating could be 10w. Presumably this incredibly low efficiency is the reason why the diode has not, until quite recently, been seriously considered as a power converter.

The biggest single factor limiting the efficiency of the diode converter is the space charge effect: electrons leaving the cathode repel each other and build up a space charge which inhibits further flow. Although closer spacing of the electrodes could mitigate this effect it turns out that to obtain useful efficiencies the spacing required is less than 0.001 in., which is virtually impossible to maintain accurately between two surfaces over an appreciable area, particularly at high temperatures. The use of external electric and magnetic fields to overcome the space charge has also been suggested; but the method currently most promising is to introduce an ionized gas (caesium) at low pressure into the inter-electrode space. Positive ions in the gas plasma then neutralize the negative electron charges and permit the current to flow.

Other Factors

Other factors influencing the efficiency of the diode converter are the electrode temperatures and work functions. (The work function is the work required to remove one electron completely from the electrode material.) Emission currents increase very steeply with temperature and work functions depend quite critically on the electrode materials. Besides having suitable work functions* the electrode materials should withstand excessive temperatures (say 3,000-3,500°F. for the cathode and about half this for the anode) without melting or undue evaporation. Tungsten and tantalum metals have received most attention but a number of other refractories are under active investigation.

It is instructive from some points of view to regard a thermionic unit as a thermocouple in which the cathode corresponds to the hot junction and the anode to the cold junction; the inter-electrode space then corresponds to the thermoelectric material of one of the loops, the " bar " in the example mentioned earlier. The other loop is, of course, the external load circuit. Now the point has already been made that the ideal thermoelectric material (if it existed) would combine the properties of a perfect electrical conductor and a perfect thermal insulator. As has been mentioned, the inter-electrode space of the thermionic diode can be made an excellent electrical conductor by the introduction of ionized gas at very low pressure†. From the point of view of heat transfer, however, this gas pressure is so low that the space is a virtual vacuum and conducts negligible heat. Thus the only heat-flow from cathode to anode (from hot to cold junction in the thermoelectric analogy) is by radiation, and this can be effectively reduced by proper shielding. In other words the inter-electrode space approximates closely to the ideal thermoelectric material, and for this reason one would expect higher efficiencies to be obtainable from a thermionic unit than from a true thermoelectric converter. An *overall* conversion efficiency of 17 per cent. with a thermionic unit was reported from the Los Alamos Laboratories in April, 1959, and higher efficiencies have presumably since been achieved (30 per cent. was predicted[21]).

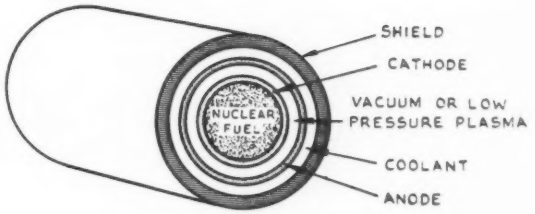

Fig. 5.—Simplified diagram of thermionic converter incorporated into nuclear fuel element

Conversion Achieved

The Los Alamos " plasma thermocouple," as it is called, represents the first direct conversion into electricity of the heat from nuclear fission. A similar device has also been reported by General Atomics[12]; this has delivered 90w at a power density of about 100w/sq.in. delivered into an external load. In this case, at the operating temperature of 3,500°F., an efficiency of 10 per cent. was achieved for the conversion of fission heat into electrical energy, but no attempt was made to utilize waste heat rejected by the converter or the efficiency and output would have been higher.

These devices can be (and are) actually incorporated in nuclear fuel elements because, in contrast to existing thermoelectric materials, the thermionic materials currently available retain their properties reasonably well under conditions of high temperature and radiation fluxes. Moreover, the gamma radiation present in a nuclear reactor helps reduce the space charge and so tends to improve the efficiency of a thermionic converter. A diagram of a nuclear fuel element incorporating a thermionic converter is shown in Fig. 5.

Like the thermocouple, the thermionic converter produces basically low voltage d.c. Although it would be possible to step up the voltage by connecting a number of elements in series as in the thermopile, this still leaves the problem of conversion to a.c. A more attractive idea to which the thermionic device particularly lends itself is current modulation within the converter, say by means of an alternating grid voltage just as in a radio triode. The a.c. output from a group of converters in parallel could then be stepped up with a transformer.

The relatively high outlet temperature (1,000-1,500°F.) for a thermionic converter suggests the possibility of a two-stage system: a thermionic converter in a nuclear reactor would reject its anode heat to the input of a second generator (thermoelectric or turbo) located outside the reactor, where it would be shielded from radiation‡. The overall thermal efficiency of such a plant would be in the region of 45-60 per cent.[2,13].

Conclusions

In this essay we have reviewed two methods which look promising for the direct conversion of nuclear heat into electrical power on a large scale. The thermionic converter has indeed already worked on an experimental scale, as we have seen[6,12],

*Other things remaining constant, there is a unique value of the cathode work function which maximizes efficiency; the anode work function should always be as low as possible.

†10^{-4} mm of mercury in a typical case.

‡In fact the first large-scale application of thermoelectric generation will probably be in such " topping-up " devices, where the materials requirements are obviously much less stringent than for devices incorporated into the nuclear fuel elements.

but both this and the thermoelectric converter will require very considerable technological development before they can profitably be incorporated into nuclear power reactors. This development will be addressed broadly to the problem of improving the efficiency of conversion, and will involve much detailed and fundamental study of the electrical and mechanical behaviour of materials under conditions of very high temperature, combined with intensive nuclear irradiation and chemical attack.

Theoretical Selection

Since it will clearly be prohibitive to investigate systematically all likely (or unlikely) materials, the selection of those to test will have to be guided to a large extent by theoretical considerations of solid state physics. There is a strong need in this connection for a concerted effort by theoretical physicists to develop a quantitative theory of radiation damage; perhaps this will be facilitated by the recently created Solid State Physics Division at Harwell, working in collaboration with theoretical physicists in universities and industry.

Because of the technological difficulties, combined with an acute shortage of suitably trained scientists and engineers to work on these novel and specialized problems, the present concensus of informed opinion about the large-scale direct conversion of nuclear heat to electric power places it at least a decade away. In this context, however, it may be relevant to recall the definition of an engineer as one who overestimates what he will accomplish in one year but wildly underestimates what he will accomplish in the next decade[14].

Possible Alternative

It is possible, though on present evidence unlikely, that something other than the thermionic or thermoelectric principle will eventually prove superior as a large-scale converter of nuclear heat into electric power. Fuel cells and magnetohydrodynamic generators have been mentioned earlier, and proposals for using these in conjunction with nuclear reactors have been put forward[13]. Such ideas are speculative, however, and do not at present amount to detailed design studies.

Other suggestions for more "exotic" devices include the use of photoelectric cells to produce electricity from the energy of nuclear gamma-rays, and the direct collection of charge from the fission fragments in a nuclear reactor. Many proposals for the latter process have indeed been carefully examined but none of them looks even remotely promising. Paradoxically, the direct conversion into electricity of the energy from controlled nuclear fusion would appear to present less difficulty: in fact it looks as if we shall understand how to do this long before we have commercial thermonuclear reactors.

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Nuclear Engineering Society 13th Annual Dinner

The Nuclear Engineering Society was formed in 1946 with the object of encouraging engineers to keep in touch with developments and to provide a forum for young engineers to express themselves on all aspects of their work, both by giving papers and taking part in discussions. Membership of the Society has now reached 1,300 and there are branches at Risley, Windscale and Dounreay. The thirteenth annual dinner of the Society was held early this year in the new restaurant at Risley.

THE THEME at the thirteenth annual dinner of the Nuclear Engineering Society was "General engineering and its support to atomic energy." The guests included many senior representatives from industry, among them the chairman and managing director of Thomas Firth & John Brown, Ltd., Dr. Charles Sykes, who made the opening speech. After briefly reviewing the history of the atomic energy industry with its birth in the difficult days of 1946, followed by the phenomenal growth of the next few years, Dr. Sykes went on to examine the present and the future. Many early estimates, he claimed, were clearly over-optimistic and in addition to this the economic and industrial background have changed out of all proportion. Oil and coal costs have been considerably reduced, which has meant that the atomic power programme has been the subject of much discussion. There is little question about long-term prospects with the coal reserves being slowly but steadily reduced and oil playing a not inconsiderable part in Britain's import problems, and according to Dr. Sykes a number of shorter-term factors are now working in favour of atomic power. Among these are the demand for higher profits by the oil-owning countries, the increasing difficulties of achieving further economies in orthodox power stations, the change-over to electricity resulting from the Clean Air Act and the expansion in electricity consumption caused by our continuing sophistication.

Dr. Sykes went on to point out that the industry was on the verge of reaping the reward for much past work, the new CEGB power stations will shortly come into operation, and the new advanced reactors will soon be providing much valuable information. In conclusion, Dr. Sykes said: "The scope therefore for technical advances is widening all the time...the present position is a stimulating and a fascinating one." △△△

Institution News

Cleaning Papers
Pinkerton Founder Award
Nuclear Propulsion

ALTHOUGH the Institution will be outwardly inactive during the summer, officers and committees will be very busy behind the scenes during the next three months. One of their principal tasks will be the collation of " subjects " for papers to be presented at meetings during the 1961-62 season.

A number of papers are being prepared on the various aspects of cleaning, maintenance, packaging and handling of nuclear equipment and materials.

Typical headings will include: (a) *Why Clean the Equipment?:* (b) *Fundamentals of Cleaning and Preservation:* (c) *Clean Rooms and Other Facilities:* (d) *Site Clean Conditions:* (e) *Packing, Preservation and Transportation, and the Problems Involved:* (f) *Tests and Standards of Cleanliness.*

Various other subjects are under consideration and members will be notified of the actual papers in due course, and of the meetings at which they will be presented.

All papers submitted by December 1st, 1961, including those on the above subject, will qualify for the Pinkerton Founder Award of 100 guineas.

Captain H. S. Atkins, DSO, DSC, RN, MIMechE, MIMarE, of Vickers Nuclear Engineers, Ltd., is to deliver a lecture at the annual general meeting on December 8th at 2.30 p.m. The subject will be " Nuclear Propulsion." △

No. 691376

Certificate of Incorporation

I Hereby Certify, that

THE INSTITUTION OF NUCLEAR ENGINEERS LIMITED

is this day Incorporated under the Companies Act, 1948, and that the Company is Limited.

Given under my hand at London this Second day of May One Thousand Nine Hundred and Sixty one.

Assistant Registrar of Companies.

(*Top, right*) **Group of members at the first Midland Branch meeting**

(*Middle, right*) **Members inspecting apparatus used to illustrate the lecture by Mr. Durrands**

(*Right*) **Mr. H. F. Jones (chairman) welcoming Mr. K. Durrands, who delivered the lecture at the Midland Branch meeting**

(*Left*) **The Institution's Certificate of Incorporation**

This article is the continuation of the lecture given to the Institution by Professor Joklik on April 18. The first part of the lecture appeared in the May issue. In this article a new method of radiation therapy of cancer is described. Gamma-convergent irradiation of the tumour is combined with the administration of chemical substances to neutralize free radicals formed by gamma radiation. Ozone treatment of the blood is used for enzymatic activation of catalase in health cells of the organism. This method permits application of considerably higher radiation doses to the tumour than previously possible.

A New Radiation Therapy of Cancer

by Otto Joklik

ONLY very recently has knowledge of somatic and genetic properties increased. Until about 15 years ago the intensity of the surrounding radiation revealed only small fluctuations, in contrast to the present situation which confronts us with a considerable increase. Considering the new hazards medicine has to focus its attention on the treatment of biological radiation effects.

Ionizing radiation acts both directly and indirectly. The indirect effects appear in particular in living tissues, since the biological basic structures are surrounded by fluid. Free radicals originate as a result of radiation, thus causing alterations. A new branch of pharmacology is searching for substances for the prophylaxis of these alterations. The administration of living cells, *e.g.*, bone marrow transplantations, does not represent true prophylaxis. Prophylaxis is accomplished only if the protective agents are already within the organism at the time of radiation exposure. The importance of oxygen with regard to radiation effect has stimulated experiments on artificial tissue anoxia. Alkaline cyanide- and cyanidehydrogen-forming molecules caused a prolongation of the survival time after lethal radiation doses. Also alcohols and sugars show a similar effect by means of oxygen utilization during decomposition. Experimentally the amines are of special interest today. Amines are in competition with free radicals. These amines, especially AET (Aminoethylisothiouronium), are able on account of their structure to form a "chemical protective wall" around the macromolecules. Thiol substances, such as cysteine and glutathion, are on account of their SH-groups centres of reactivity with respect to free radicals.

The third group consists of those protective substances which prevent a decomposition effect of free radicals. Substituted fat-soluble derivatives of the naphthols and polyphenols have these properties.

Finally, chelate-forming substances are not only interesting on account of their radiation protection effect, but also because these substances have properties which counteract the ageing process.

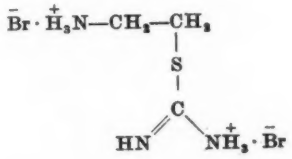
Advantages of AET

The search for further and better chemically active substances must be continued. AET (Aminoethylisothiouronium) has the unique advantage of good stability, relatively low toxicity, excellent protective activity and effectiveness when administered orally. AET is a S, β-Aminoethylisothiouronium bromide hydrobromide having the

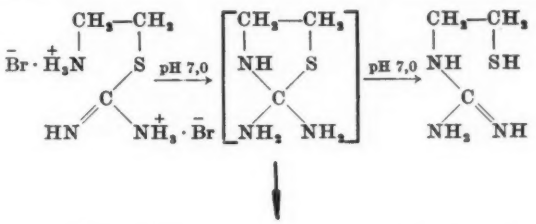
Table VII.—Survey of the SH Compounds as a Means of Radiation Protection

	Molecular weight	Toxicity (LD 50)		Radiation protection		Therapeutic index	Per cent. surviving on 28th day	No. of animals	*p*-value for checks	*p*-value for AET Cl. Hcl
		mg/kg oral	mMol/kg oral	mg/kg oral	mMol/kg oral					
Cystin. HCl	157	2500	15.9	1900	12.1	1.31	17.0	680	<0.01	<0.01
α-Homocystinthiolacton	169	1150	6.8	1000	5.9	1.15	21.0	100	<0.01	<0.05
N-Acetyl-α-Homocystinthiolacton	158	1450	9.2	1200	7.6	1.21	10.0	280	<0.01	<0.01
β-Aminoethylisothiuronium Br. HBr	280	1200	4.3	1000	3.6	1.20	25.0	120	<0.01	=0.05
β-Aminoethylisothiuronium Cl. HCl	190	710	3.75	400	2.1	1.78	38.0	160	<0.01	—
β-Mercaptoethyl guanidine	119	(350)	2.94	200	1.68	1.75	12.0	200	<0.01	<0.01
Up to β-guanidinoethylsulphide	236	—	—	250	1.58	—	2.0	120	—	—
		intra-peritoneal		intra-peritoneal						
β-Mercaptoethylguanidine	119	—	—	100	0.84	—	8.0	120	<0.01	<0.01
Cysteamine	77	(210)	2.75	150	1.95	1.41	22.0	100	<0.01	<0.05
Arterenol	169	(300)	1.77	200	1.18	1.5	16.0	80	<0.01	<0.05
Serotonine	176	(200)	1.14	165	0.94	1.21	35.0	80	<0.01	—
Checks	—	—	—	—	—	—	—	860	—	—

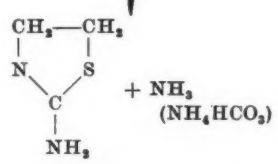
empirical formula $C_3H_{11}N_3SBr_2$ and a structural formula:



The molecular weight is 281, the composition 12.8 per cent. carbon, 3.9 per cent. hydrogen, 14.9 per cent. nitrogen, 56.8 per cent. bromine and 11.4 per cent. sulphur. It is a white, crystalline solid, having a melting point of 188-189°C., very soluble in water, sparingly soluble in isoporopyl alcohol. The normal *p*H of AET is 3.5. AET is stable when pure and dry. In neutral solution AET undergoes rearrangement through migration of the ureido group to the N-atom forming 2-Mercapto-ethylguanidine (MEG). In the presence of bicarbonate ion (or carbonic acid) ammonia is split off and 2-Amino-thiazoline (2 AT) produced.



(AET.Br.HBr)
(unstable intermediate)
(MEG)
with bicarbonate buffer (*p*H 7.0) this reaction occurs as well
AET treated with carbonic acid (*p*H 4.5) yields 2 AT exclusively.
(2 AT)



Experiments with isotopically labelled compounds have demonstrated that MEG rapidly penetrates into tissue. It can therefore be available for detoxification of free radicals in such key organs as liver, kidney, spleen and bone marrow which are especially sensitive to radiation damage.

According to the most widely held views on radiation damage, it is believed that the capacity of MEG to combine with and detoxify free radicals accounts for its unusually effective ability to protect against radiation damage. The formation of free sulphohydryls *in situ* has other interesting possibilities for physiological studies, as for example, enzyme activation. AET is therefore expected to be an important new biological tool as well as a specific prophylactic against radiation damage.

The formation of free radicals and of hydrogen peroxide has been shown in the following way. As α-particles, electrons and γ-rays produce ionization in matter, it would appear logical to study more judicially the chemical effects of ionizing radiations as a background for explaining a number of the observed biological effects. With the advancement of the free-radical theory by Weiss (1944), the study of radiation chemistry received a new impetus. Although there is a parallelism between photochemistry and radiation chemistry, there is an important difference. In photochemistry, the absorption of the radiation is specifically connected with a certain chemical group or bond. However, with ionizing radiations the absorption is practically independent of the chemical bonding and depends on the mass of the absorber. In the case of substances in dilute solution, most of the absorber is the solvent, and it is to the solvent that one must look for changes. The following equations outline what occurs when water is treated by ionizing radiations:—

$$H_2O \longrightarrow H_2O^+ + e^- \quad . \quad (1)$$

The positive water ion, H_2O^+, dissociates as follows:

$$H_2O^+ \longrightarrow H^+ + OH \quad . \quad (2)$$

The electron, from (1), combines with a normal water molecule:

$$e^- + H_2O \longrightarrow H_2O^- \quad . \quad (3)$$

The resulting negative water ion dissociates:

$$H_2O^- \longrightarrow OH^- + H \quad . \quad (4)$$

Thus the ionization of water produces positive and negative water ions, which dissociate, producing free hydroxyl radicals and free hydrogen atoms. If the hydroxyl radicals and hydrogen atoms are close enough together, they can recombine (back reaction):

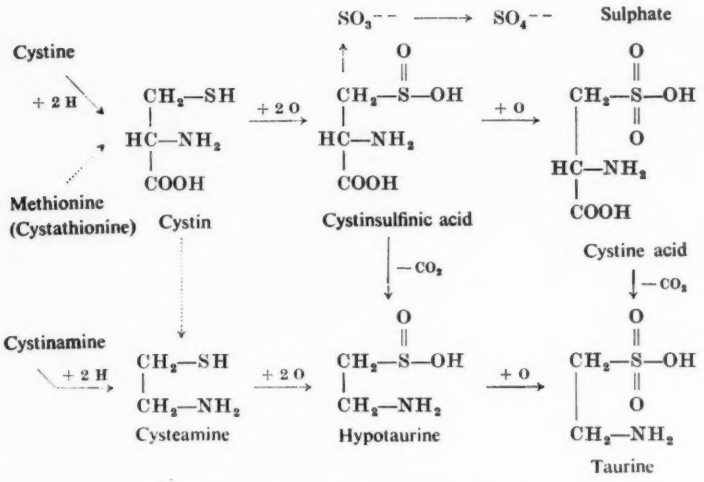
$$H + [OH] \longrightarrow H_2O \quad . \quad (5)$$

However, on a molecular scale, the distance between the H and the OH is so great that other reactions may occur.

The OH radical has the power to oxidize oxidable substances and the H atom has reducing power. Therefore, an oxidizable solute in a solution will be oxidized by ionizing radiations and a reducible solute will be reduced. The probability that ionizing radiations have a direct effect on solute is small, especially when one considers the vastness of intermolecular spaces (solvent) as compared with molecules of minute size in solution.

Water radiation

The radiation chemistry of water and of aqueous solutions may be summarized in general as follows: (1) oxygen, if present, will remove the H atoms for which it has an affinity and will tend to prevent recombination of the H atoms and the OH free-radicals; (2) hydrogen in an oxygenated aqueous solution eliminates the interaction of [OH] and HO_2 and, therefore, H_2O_2 tends to be formed; (3) hydrogen enhances the decomposition of H_2O_2; (4) the hydrogen free-radical is very light and diffuses rapidly (probably 150 Å from the track of the ionizing particle). The OH radical is heavier and probably only 8 Å from the path; (5) the H atom is predominantly active because of its relatively simple structure and its rapid diffusion; the OH radical is the next active, and the HO_2 radical is the least active of the three; (6) the primary effect of ionizing radiations on solutes is, therefore, indirect, via formation of free-radicals in these solutes. The most important link in the biological effect of ionizing radiation is its influence on high-polymeric nucleoproteids and nucleic acids, which leads to the appearance



Cystine, cysteamine, and taurine mechanism

of abnormal fission products of these biologically vital polymers. Disturbances in the structure of the nucleic acids are reflected in the synthesis of specific protein enzymes, which brings about correlated disturbances in the various steps of the metabolic process.

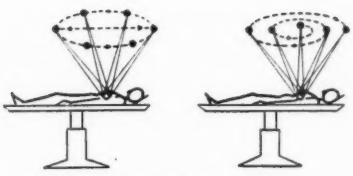
These metabolic disturbances are increased by the change in the adsorbability of the enzymes on the surfaces of the microstructures and by the change in permeability, which can also be considered a result of the depolymerization of the complicated high-molecular protein substances in the living tissue. Thus, in view of our present knowledge, there is urgent need for further study of the changes which are brought about in the structure of high polymeric substances in the living organism by ionizing radiation.

Blood transfusion

Following on the discovery of the blood groupings and the Rhesus factor, it became possible to transfer, blood without danger, from one human being to another. Generally, venous blood is used for such transfusions, *i.e.*, blood poor in oxygen and rich in decomposition substances (catabolytes). Bier in Germany and Henschen in Switzerland were the first to try about 40 years ago to enrich this oxygen deficient blood with oxygen before re-infusion. Henschen succeeded in revitalizing patients suffering from severe narcosis effects and in saving them from narcosis death through blood enriched with oxygen. In 1930 Havlicek irradiated blood and also body liquids, *e.g.*, abdominal liquid, with ultra-violet light and then reintroduced it into the body. The results were astonishing.

U-V radiation

In 1933, Braun in Germany and Knott in America irradiated blood with ultra-violet rays and subsequently reinjected it. They experienced astonishing success in cases of bacterial infections. Later, in 1940, Haas and Kast (collaborator of Henschen) tried to combine both methods by irradiating blood in a quartz cylinder with ultra-violet rays from outside. Chiefly asthmatics were treated by them. This method did not take on, as losses of blood were too great through coagulation processes. Unfortunately Kast died that same year, so that his experiments stopped in their initial stages. From 1946 to 1948 Wehrli tried to improve



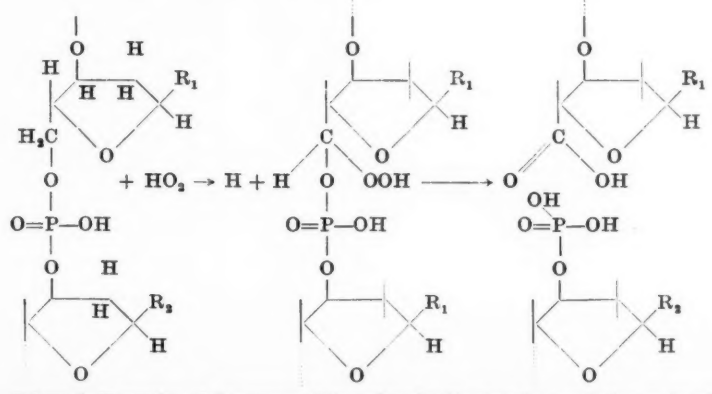
Gamma-Convergency technique

the method of treatment of the blood with oxygen and ultra-violet rays in experiments on himself with specially designed and constructed equipment. This equipment is described in a book by Max Ostermann (Praktikum der Physikalisch-Diaethetischen Therapie, third edition, 1952). Thus cases of asthma, silicosis and disturbances of circulation were treated with good results.

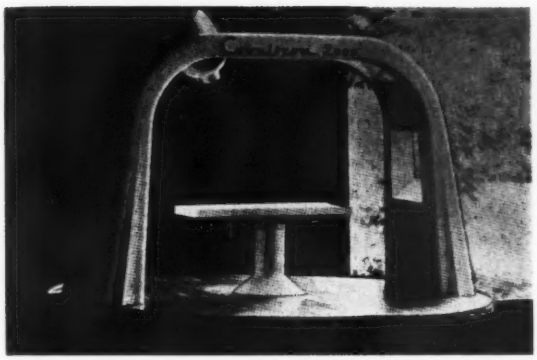
Coagulation

The problem of coagulation danger was solved by means of various anticoagulation agents. After trying out various experimental models of apparatus for treatment, the following process has now proved itself: oxygen, introduced in delicate bubbles under constant pressure through a glass grain filter carries along from a container venous blood, taken from the patient, by means of a transporting tube, in the shape of small oxygenated foam bubbles and transports it, already arterialized, into a radiation chamber in which the bubbles are moved slowly past a special ultra-violet light tube on the top of the chamber. The irradiated blood bubbles collapse and the treated blood drips into a container from which it is taken for re-infusion.

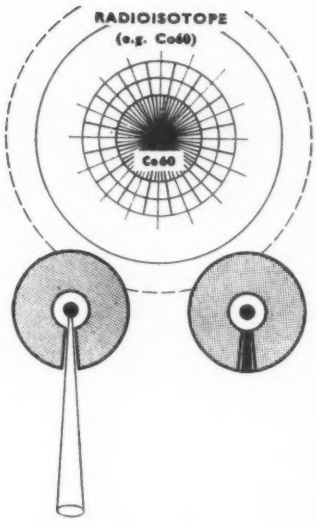
The facilitated collapse of the foam bubbles occurs under the influence of the ozone originated



Schematic illustration of the rupture of the polynucleotide chain by a radiation produced free radical



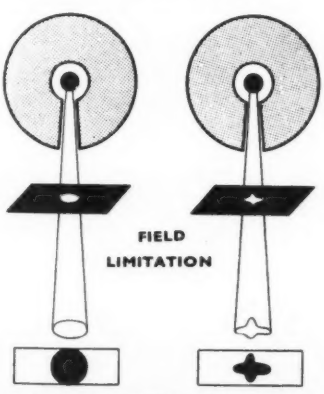
(Left)
Cobaltron 2000



(Right)
Principle of the radiation head container with the Co60 source

by the ultra-violet irradiation. The apparatus itself, the transporting tube and the glass grain filter situated below the latter are all detachable so that they can be cleaned efficiently.

Through the foaming of the blood, the thickness of the bubble walls is reduced to a fraction (0.001 mm). The penetrating ultra-violet rays and their fraction light are thereby also enabled to act intensively on the deeper foam layers. After measurement with photographic films that were exposed through the bubble layer, a penetration capacity of the ultra-violet rays to a depth of about 200 foam bubbles was ascertained. In this connection it must be pointed out that in the irradiation chamber 30 to 40 bubbles are superimposed one over another while passing below the ultra-violet rays tube. The blood, rendered bright red and flowing more freely after irradiation, leaves behind in the irradiation chamber a colourless lamina structure of clotted fibrin, more or less strongly developed according to the constitution of the patient. In the case of severe arteriosclerosis and patients with low clotting times, the fibrin quantity is often noticeably increased. There is no evidence of any serious incident or case of Icterus caused by transfusion in over 20,000 statistically recorded blood bank transfusions and over 15,000 re-infusions. The American School assumes that Icterus Virus is tied to the fibrin (European Congress for Haematology in Freiburg i. Br., 1956). Furthermore, certain forms of virus (Parke-Davis, Poliomyelitis) are supposed to be sensitive if exposed to ultra-violet rays. Bonifacio, Lang, Steinbart and others observed a volume increase of the Erythrocytes from 7 to 9 micro, which Busch puts parallel to the oxygen transfer capacity in his chart.

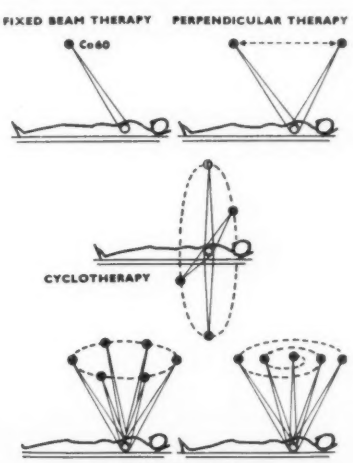


Principle of collimator and additional field limitation to the shape of the tumour

Normal treatment

In the normal treatment of small quantities of blood, *i.e.*, 30-55 cc or, possibly 100 cc, the blood is taken from the collection receptacle by syringe and injected into the patient slowly i.v. or also i.m.

The oxygen is supplied from an oxygen cylinder by way of a reduction valve and cotton wool filter under pressure equalization through an overflow rate. It reaches the blood, therefore, under constant pressure, thus preventing any excessive strain on the erythrocytes. All the blood remains in the haematogenous oxygen treatment equipment protected from any outside contact and, therefore, sterile. The mechanism of action of the haematogenous oxidation therapy was, at first, not clear.



Various radiation therapy techniques

The biophysician Romoli Venturi (Sull'Eziologia delle Neoplasie acenni di Terapie casuale, Milano, 1949) as well as the clinician Wenning, Graz (Veraenderung der Blutelemente durch UV-Bestrahlung in Sauerstoffatmosphaere, Wiener Medizinische Wochenschrift Nr. 51/52, 1956) observed *inter alia* a negative loading of the erythrocytes after treatment. Kollath spoke of chain reactions in the blood enzyme system. H. Steinbart proved that after this treatment increased proteolytic enzymes are present in the blood. Pischinger showed in intensive investigations (1952/53) with the Beckmann Spectrograph that in this treatment the saturated fatty acids in the treated blood are changed into highly unsaturated ones. According to Marquardt, the UV-oxygen treatment influences unquestionably the aerobic potential of the blood.

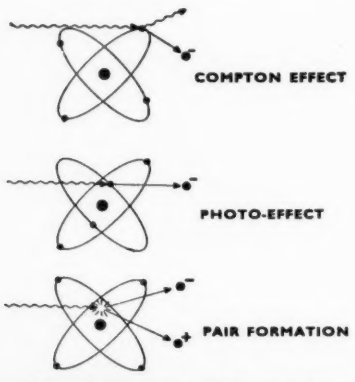
In the meantime, a very important contribution in explanation of the HOT effect has been furnished by Prof. Albers who, on the occasion of the therapeutic week 1957 in Karlsruhe, reported about the work done in the Institute for Therapeutical Chemistry at Mainz University. Proceeding from the critical question

of whether it is at all possible to prove a chemically ascertainable alteration of the blood particles in reproducible model experiments, to which could be attributed the " alleged " successes, he was able to prove the formation of novel peroxides from unsaturated combinations of the blood under the influence of ozone; these showed themselves highly effective in transferring oxygen. Therefore it is not the comparatively small quantity of oxygen which is introduced into the patient additionally as oxyhaemoglobine through arterialization of venous blood from the patient that is responsible for the therapeutic effect, but the capacity for using the oxygen circulation in the blood *per se* that is stimulated through catalytic activation of those peroxides. Small, but especially over extended periods, continuously active quantities are inherent in the nature of catalysts; they resemble therein the enzymes (compare also lecture Wehrli, Haematological Congress in Copenhagen, 1957: " How to prevent unwanted Effects following Blood Transfusions ").

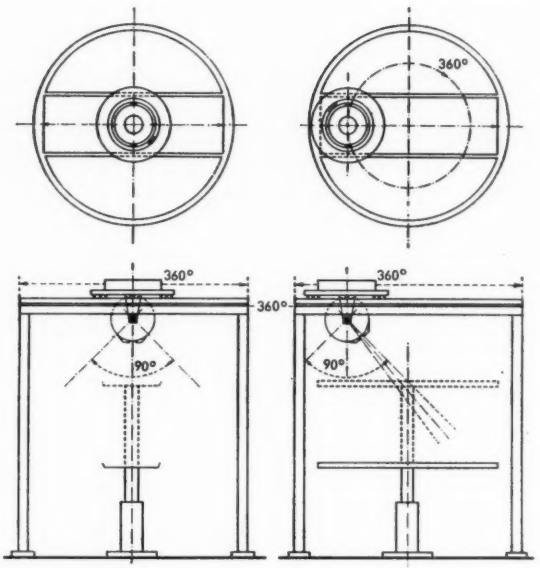
In heart and vascular diseases the therapy is definitely beneficial. It seems plausible that other ailments, too, should benefit by this treatment.

Cancerous growths

Treatment of cancerous growths might be mentioned which appears feasible based on furtherance of the oxygen utilization made possible by Albers and considering the known results of Warburg. (Compare herewith V. W. Shuster, Department of Zoology, Duke University, Durham: " Effects of Oxidized Fatty Acids on Ascites Tumour Metabolism.") For the present study, two facts resulting from the haematogenous oxidation treatment of the blood are most interesting and important; these are the increase of the oxygen utilization within the blood of the patient and the catalase activation in the living cell. Catalase activation is especially important because of its function as neutralizing agent for the decomposition of hydrogen peroxide formed in the cells by ionizing radiation. The selective action of the X- and γ-rays is explained by Warburg by the fact that the cancerous cell of partially anaerobic constitution is not provided with the enzyme catalase and thus in consequence may be destroyed by the cell poison, hydrogen peroxide, produced under ionizing radiation, whereas the same hydrogen peroxide is neutralized by the catalase in the healthy cells of the tissue.



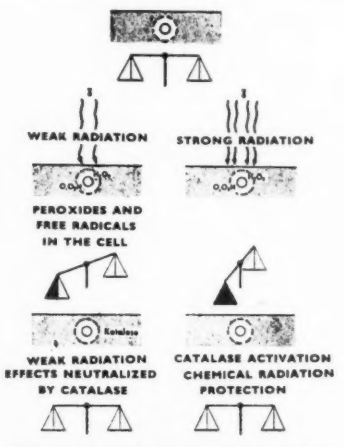
Schematic illustration of the Compton Effect, Photo-Effect and Formation of pairs



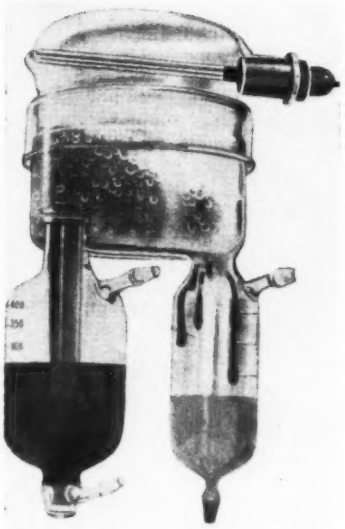
Schematic diagram of Cobaltron principle

Co60 teletherapy

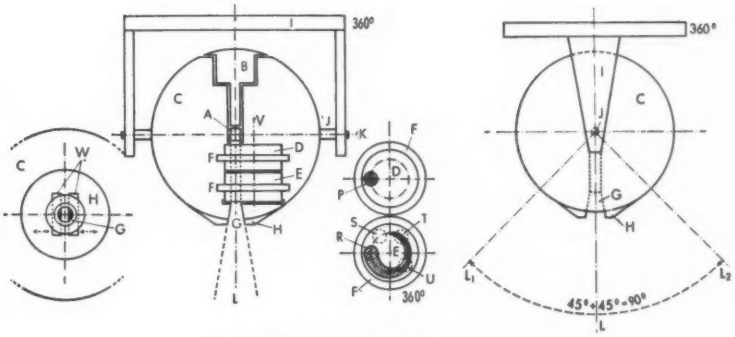
The gamma irradiation of the tumour is performed by means of a Co60 teletherapy facility of new design which realizes for the first time the gamma convergency treatment with a multikilocurie Co60 gamma source contained in a special container circulating in synchronized circular or spiral movements above the horizontally placed patient. The Co60 gamma convergency unit (Cobaltron) weighs some 8,000 lb, can be used for Co60 gamma sources of high specific activity up to 5,000 curies, and provides for a dose rate of up to some 200 r/min at a SSD (source-skin-distance) of 1 m. Both stationary and rotation techniques are applicable. The Co60 gamma source is provided with a triple safety lock (electric, magnetic and manual by means of a hand-driven flexible spindle) thus being independent of electric power supply. A special collimator provides for an irradiation field in any dimension from 20 × 20 mm up to 400 × 400 mm and an additional device reduces the irradiation field from its geometrical shape to the shape of the tumour, thus reducing the accumulation of radiation doses in the healthy tissues of the patient. Fully automatic electronic steering enables programming



Schematic illustration of the effectiveness of the body's own defence against weak γ-radiation



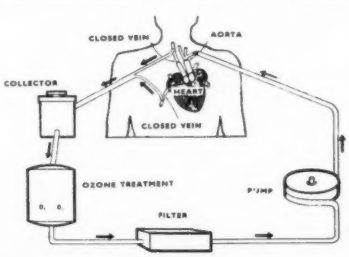
Apparatus for U-V-oxygen blood treatment



Head of Cobaltron (A—radiation source)

of various irradiation programmes by means of a magnetic tape or punched cards, thus keeping a record of the irradiation for reproduction, control, documentation, etc. A built-in analogue computer steers automatically the complete irradiation process, thus saving considerable time in adjusting the irradiation machine.

Special radiation measurement instruments in the shape of thick needles which may be placed on or in some cases in the body are connected to visual, graphic and acoustic recorders provided with an automatic maximum level control, thus avoiding overdosage. Radiation protection material is incorporated in the support of the installation, thus reducing considerably the necessity and cost of supplementary and additional radiation protection at the premises. The irradiation facility has a special shielded container for sterilization of surgical material, sutures, dressings, etc., by gamma radiation of the teletherapy Co60 source, thus making use of the maximum yield of the radiation source outside working hours and during holidays. Work is now being done on the possibility of combining the Cobaltron with a machine designed for the establishment of a second artificial blood circuit, thus enabling irradiations of certain parts of the body under artificial blood circulation.



Principle of the separated blood circulation

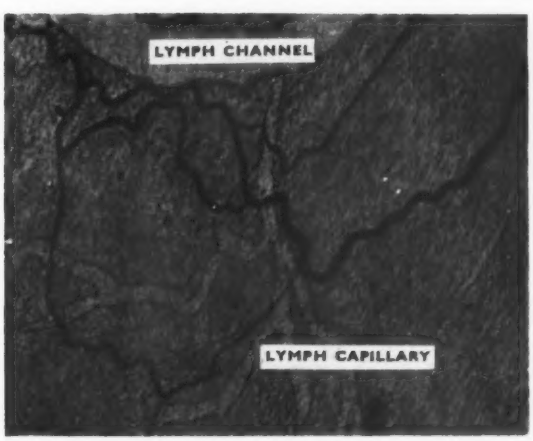
Tolerances

In the application of the X-ray therapy of cancer the skin tolerance of the patient is the limiting factor for the dosage. In Co60 teletherapy the tolerance of the healthy tissue and not skin tolerance is the dose limiting factor. Generally speaking, as yet there is no way of administering a relatively high dose in the tumour without seriously damaging the healthy tissue which surrounds the tumour.

The ionizing radiation provokes in the living cell large scale formation of free radicals and organic peroxides, mainly hydrogen peroxide. Hydrogen peroxide, being a strong cell poison, acts destructively on the living cells. The body's enzyme catalase is capable of neutralizing a certain, relatively small amount of radiation produced hydrogen peroxide in the cell. By a blood treatment using the haematogenous oxidation treatment of the blood by ultra-violet rays in the presence of oxygen and consequent formation of ozone, a remarkable catalase activation is achieved which neutralizes further quantities of radiation induced hydrogen peroxide in the body.

Decomposition of the nocive free radicals in the body, especially in such important organs as liver, kidney, spleen and bone marrow is achieved by certain chemical agents containing a free SH-group, *e.g.*, AET (Aminoethylisothiouronium), administered orally some 30 min before radiation exposure.

It is evident that a considerably higher radiation dose may be administered in the tumour without any damage to the surrounding healthy tissue, so long as appropriate catalase activation by an ultra-violet ray and oxygen treatment of the blood has taken place and chemicals



Microphotograph of part of the Lymph system

capable of decomposing the radiation induced free radicals in the body have been administered. This new method selectively affects the tumour and cancerous tissue where there is no regular supply of catalase owing to the degenerated and partially anaerobic state of the cancerous cell; so radiation produced hydrogen peroxide being strong cell poison may easily destroy the cancerous cell, the healthy cells being in the meantime protected by activated catalase.

Blood treatment for catalase activation may be applied in a split up and separated blood circuit in certain cases, in which the cancerous tissue or tumour is being connected to and supplied with an artificial blood circuit containing no catalase at all, whereas the parts of the body surrounding the tumour with their healthy tissue are supplied by a second artificial blood circuit containing activated and enriched catalase, which thus neutralizes the radiation effects of the ionizing radiation in the healthy tissue by decomposing and neutralizing the radiation produced hydrogen peroxide.

Lymph circulation

A further very important method is combination of Co60 teletherapy of cancer with the administration of certain chemicals and agents stimulating and increasing the lymph circulation. By an increased lymph circulation there can be achieved a preferential and much earlier elimination of toxines, cell fragments and even cancerous fragments from the body with a consequent disintoxication of the whole organism.

By the methods here illustrated much higher single treatment radiation doses may be administered in the tumour or in the cancerous tissue without damage to the healthy tissue of the body. In addition, a better therapeutical effect and shorter total irradiation times combined with less discomfort for the patient may be achieved, a fact of considerable importance particularly for the preoperative irradiation of cancer.

Finally, the physical blood treatment for catalase activation, the chemical antiradiation agents with free SH-groups and the agents for increasing the lymph circulation with consequent decomposition of hydrogen peroxide, neutralization of free-radicals and toxines elimination, may be considered a remarkable method for the prophylaxy and for the treatment of even serious radiation injury to man, particularly on account of the relatively easy and simple methods of administration.

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Book Reviews

The Entry of Fission Products into Food Chains, by J. F. Loutit and R. Scott Russell. Published by Pergamon Press. 154+XII pp. Price 45*s*.

This is Volume 3 of the section on Biological Sciences in the Progress in Nuclear Energy Series, and a welcome addition to this ambitious library of atomic energy literature. " Operation Buffalo," a series of nuclear weapon tests undertaken by the British at Maralinga, Australia, provided an excellent opportunity of studying the movement of fission products into food chains. The investigations were the outcome of proposals by the Medical and Agricultural Research Councils and the Ministry of Agriculture, Fisheries and Food, and the actual experimental work was the joint responsibility of the Biological Target Response Group, the Radiological units of MRC and ARC, and the MAFF. The ten papers contained in this volume illustrate clearly the complexities of the problems, and how foolhardy it is to express opinions upon the hazards or the harmlessness of weapon fall-out without an adequate overall knowledge of the factors involved. R. Scott Russell and J. V. Possingham, in " Physical Characteristics of Fall-out and its Retention on Herbage " point out that the biological availability of fission products is high, a finding at variance with earlier assumptions that weapon fall-out would be only sparingly available for absorption by animals and plants. The reason for the differences lies in the different geological conditions encountered in the siliceous sands of Nevada and the calcareous soils in Maralinga. There was evidence that Sr89 deposits on the ground were depleted relative to the total deposition by factors from 3 to 22. Work on uptake by cereals indicated that hazards arising from consumption of contaminated flour were smaller by a factor of at least 1,000 than those from milk, contamination here referring to Sr89/90. Activities due to I131, Sr89, Ba-La140, Te-I131 and Mo-Tc99 were well absorbed from the alimentary canal in Dutch rabbits, absorption of fission products from weapon clouds being about the same as from liquid doses of separated pile fission products. Ru and rare earths presented little radioactive hazard. G. E. Harrison and W. H. A. Raymond describe the radiochemical procedures used in this work, based on the methods of Cook and Crouch; G. E. Harrison writes also on the calculation of doses to the intestinal tracts of rabbits. After the feeding of mixed fission products from the Maralinga trials to lactating dairy cows, it was found that the major part of the activity in milk and urine was due to iodine, but there were important contributions also from Ba140, Sr89 and Te132. Wide variations in the amounts of I131 and Sr89 secreted in milk were mainly the result of differences in milk yield. In sheep, wild and laboratory rabbits, experiments within 10 days of the explosions revealed that not more than 10 per cent. of the gross activity was absorbed from the intestinal tract, and there was a delay in the rumen. Certain fission products are cleared from the blood by tissues and excretory organs and then, when excretion exceeds absorption, the soft tissues are rapidly cleared. Rabbits gave more individually variable results, there being no difference between wild and tame animals. There is obviously a considerable radiation hazard to cells of the gastrointestinal tract, especially in the rumen of the sheep. A recording single-channel γ-spectrometer revealed the presence of I131, I132, Xe133, Xe135 and Te132 in the thyroid of sheep fed on explosion fission products. The well-type γ-scintillator set on a narrow channel to measure the maximum of the main γ-energy peak was considerably more efficient than the M6 liquid counter. By way of general conclusions, it is pointed out that hazards from nuclear weapons are multitudinous. For those who survive the immediate effects of blast and γ-flash, the contamination of food with radioactive debris may be a major risk. The Maralinga researches have contributed largely to settling some of the many questions here. Early radiation risks are from iodine, and the bone-seekers offer later hazards. Fission products in fall-out will show low biological availability only when deposited on relatively large particles, and even then only when there is much fusion of particles. Further problems arise with high yield " clean " bombs, when fission product activity may be exceeded by that due to induced radiation. This needs much more investigation. This is a volume which deserves a careful assessment by level-headed people. The layman should be told of these results, if only to dispel some of the illusions and misconceptions which have arisen from results of earlier work carried out under very different conditions. My only criticism of this book is that there is a lack of uniformity about the papers—in some cases summaries are given at the end of a paper, in others at the beginning. F.R.P.

Russian-English/English-Russian Nuclear Dictionary (in two volumes). Published by Central Editorial Board, Foreign language scientific and technical dictionaries, Moscow, 1960. Available from Collet's, 44 and 45, Museum Street, London, W.C.1.

Twenty thousand terms are contained in the two volumes of this dictionary, providing comprehensive coverage of the following fields: theoretical and experimental nuclear physics; thermonuclear research; reactor physics; engineering and materials; nuclear fuels and processing; isotope technique; radiation protection and nuclear equipment. In addition, the most common radiobiological terms and the names of uranium- and thorium-bearing minerals are covered. Abbreviations used in Soviet literature and a table of elements and isotopes are included in a supplement. Use was made during compilation of the dictionary of the proceedings of the 1st and 2nd International Conferences on the Peaceful Uses of Atomic Energy held in Geneva in addition to the basic scientific journals and monographs on nuclear science and engineering.△△△

ISOTOPE SEPARATION AT OAK RIDGE

OAK Ridge National Laboratory, America's major producer of isotopes, has recently completed steps to increase separation of stable isotopes by a factor of six. Testing of 24 reactivated electromagnetic separators has been successfully completed, bringing Oak Ridge's calutron total to 28.

Enriched stable isotopes are separated in giant mass spectrographs, called calutrons. A calutron can be either a beta or alpha type. Both beta and alpha calutrons depend on differences in masses of isotopes for separation.

A rapidly moving team of positively charged ions of the element being processed is passed through a magnetic field, and the different isotopes are resultantly "bent" in different amounts by the field and hence travel slightly different paths. By placing collector pockets in the proper position, it is possible to collect enriched isotopes. These are then chemically purified.

The 24 reactivated separating facilities will be beta calutrons In separators of this type, the 24 in. radius of the arc through which isotopes travel is exactly half the size of the arc in an alpha calutron, and separation of isotopes is greater. For this reason, when the mass difference is one—in isotopes such as Tin-112—alpha calutrons are preferable.

When Oak Ridge started separating stable isotopes in 1945, four calutrons converted from U235 pilot plants were available. At that time a programme of separation of elements up to element 83 was started. More than 250 stable isotopes are now available. This represents all the elements having isotopes except inert gases. Isotopes do not occur naturally in approximately 20 elements.

The addition of the reactivated calutrons will bring Oak Ridge's goal of separating highly enriched gramme quantities of all isotopes—and purer isotopes—closer to reality.

Before the addition of these calutrons, gramme quantities of enriched isotopes were readily available only if 1 per cent. or more of an isotope was present in the natural occurring element.

Purer Isotopes

The desire of reactor scientists to accurately measure nuclear cross-sections of isotopes, a property of an isotope's nucleus to absorb or scatter neutrons, has created a need for increased quantities of higher purity isotopes. Definite knowledge about nuclear cross-sections of all nuclei will greatly advance reactor development by pointing out desirable materials of construction. Approximately 75 per cent. of all the separated materials are used in nuclear cross-section studies.

Calcium-47, used as a tracer in medical studies, is an isotope that is being given increasing attention and study at the Laboratory. The short half-life of 4½ days that this isotope has makes it especially useful in bone cancer studies. Previously, calcium-45 was utilized in such tests, but its 160-day half-life makes it less desirable for most applications. The beta and gamma ray activity of Ca47 disappears in three weeks compared with 2½ years for Ca45.

Ca47 demand

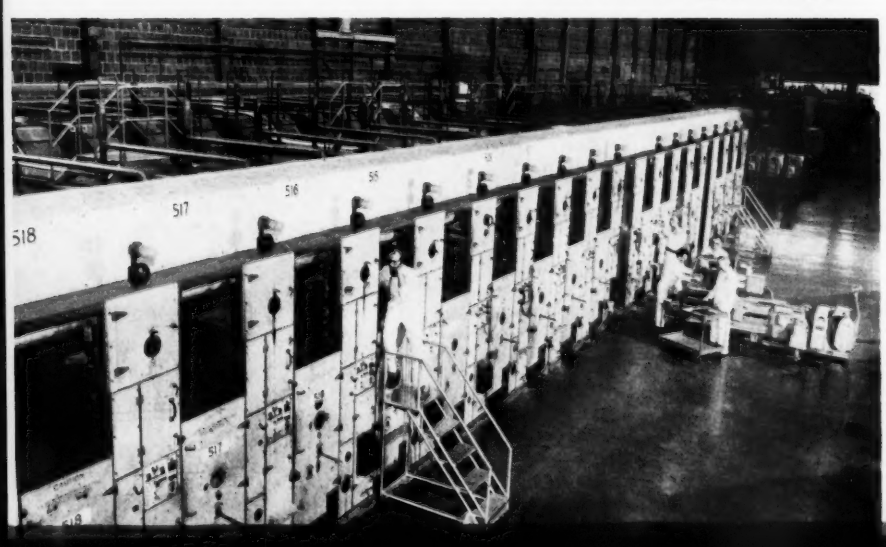
The potential demand for Ca47 if a product sufficiently free from Ca45 can be separated is estimated to be up to 500 millicuries/year.

Ca47 is obtained by bombarding Ca46, available only in quantities of less than one gramme, with neutrons. Ca46 has a natural abundance of only 0·0033 per cent., and, consequently, 1 kg of natural calcium is necessary to obtain six mg of Ca46. To date, only about 48 mg of Ca46, with an average purity of 15 per cent., have been separated.

Several other methods for obtaining Ca47 are currently being considered. It may be possible to bombard Ca48 with protons in the Laboratory's 86 in. cyclotron and produce a (p,pn) reaction which will result in Ca47. Ca47 may also be obtained by neutron bombardment of Ca48 (n, 2n) or titanium-50 (n, α) Ca47 in a reactor. Neutron bombardment of Ca48 gives very low yields of Ca47. Ti50 (n,α) Ca47 reaction, which requires higher neutron energies than are routinely available, is now being investigated.

The addition of the 24 reactivated electromagnetic separators to Oak Ridge's stable isotope separation facilities is a part of a continuous programme of improvement and development intended to keep pace with increasing demand for higher quantities of higher purity stable isotopes. △△△

Beta track formerly used for separation of uranium-238 now processing all chemically-active elements having stable isotopes.



Classroom and Laboratory

Arising out of a proposal by Dr. F. R. Paulsen, at a Council Meeting of the Institution of Nuclear Engineers, several hundred teachers of nuclear science were asked to report on simple apparatus and methods used or those which might be useful for practical demonstrations in instructional courses. The response was enthusiastic. From all parts of the world, from teachers in Universities, High Schools and Colleges, from research workers, manufacturers and public relations experts, have come many ideas. As a service to teachers, and also to other workers in nuclear fields, we are now publishing the many suggestions put forward. Each suggestion carries the identity of the person who put it forward, and also a reference number. The latter will facilitate enquiries sent in by readers requiring further information. Readers are invited to submit suggestions for inclusion in this feature

No. 50 Useful booklets and film strips

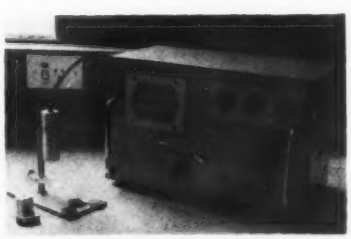
Mullard Educational Service, U.K.

The Mullard Educational Service has made available some excellent little booklets entitled " Demonstrations and Experiments in Electronics." Examples of these are: No. 1—Photocells; No. 2—A Transistor Demonstration Board; No. 3—An Improved Power Pack for Schools; No. 4—Comparison of Gas and Vacuum Tube Grid Characteristics; No. 5—High Impedance Voltmeter; No. 6—An E.H.T. Voltmeter; No. 7—Simple Audio-Frequency Oscillator; No. 8—High Gain Single Valve Amplifier; No. 9—Hysteresis Loop Displays; No. 10—Second Power Pack for Laboratory Use. The Mullard Educational Service has also produced several invaluable film strips, obtainable from Unicorn Head Visual Aids, Ltd., of 42, Westminster Palace Gardens, Victoria Street, London, S.W.1. In black and white, and costing 15*s.* each, are the following examples which will prove useful in teaching the fundamentals of certain electrical aspects of nuclear science: E 21—Magnets and Magnetic Materials (24 frames); E 28—The Thermionic Valve (Diode and Triode) (29); E 29—The CR Oscilloscope (22); E 31—Discharge Lamps (22); E 38—Rectification (32); E 1—Introduction to Electronics (29); E 38; E 2—Electronic Devices 1 (Electron Tubes) (30); E 3—Electronic Devices 2 (Semi-conductors) (31); E 4*a*—Basic Valve Circuits, Parts I and II (31); E 4*b*—Basic Valve Circuits, Parts III and IV (20); E 6—Principles of the CR Tube (21); E 7—The Meaning of Valve Characteristics (23). The Mullard films, also valuable to teachers, are available on free loan from Torrington Place. Examples of these are: " Modern Magnetic Materials " (16 min); " Manufacture of Junction Transistors " (21 min); From the EFVA Film Library, Brooklands House, Weybridge, Surrey, can also be obtained on free loan, films such as "Principles of the Transistor " (19 min); " Discharge through Gases " (11 min); " Vacuum Practice " (16 min); " The Linear Accelerator " (12 min); " Photo Emission " (18 min); and " Conquest of the Atom " (22 min, in colour).

No. 51 A nuclear radiation counter

D. J. Carswell, Australia.

This instrument was developed to record all types of radiations and to operate with more than one type of detector. It had to have high efficiency and reliability, generating no spurious pulses and showing no variations with fluctuations of 10 per cent. in the a.c. mains voltage. It had to be able to handle high count rates without coincidence loss, and it had to be simple, easy to operate, and not liable to damage during operations. Finally, though this was a very important point for most schools, it had to be cheap to build, the cost not exceeding £25.



Nuclear radiation counter

An interesting feature is the octal plug at the back, making the device suitable for use as a power supply for cathode ray tube experiments.

The counter fits a commercially-available mass-produced instrument case, for operation from a GM or a scintillation-detector. Operation may be from any GM tube made by Mullard, Philips, or 20th Century.

Counts are displayed on a bank of three Dekatron tubes, counting accurately even above 10,000 c.p.m. There are only two knobs on the front: a multiposition switch to select the EHT, and a three-position switch giving positions for " count," " stop," and " reset." At the rear, a toggle switch operates a speaker, independently of the scaler, and of the setting of the front three-position switch.

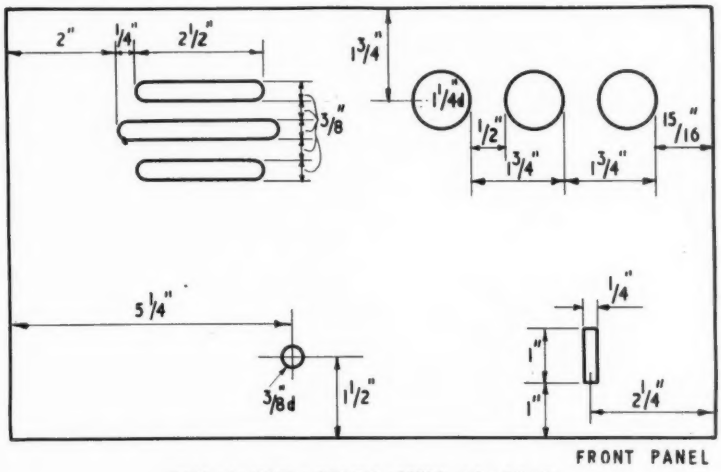
The ratemeter drive potential is connected to a rear plug, so that a meter can be plugged in when required. An ample steady d.c. voltage, proportional to the count-rate, is available at the plug to operate most meters such as a 0-10v a.c. meter. Meter sensitivity is variable through a series resistor.

The rear octal plug carries 6.3v a.c. on pin 7, 400v d.c. on pin 3, variable EHT up to 1200v a.c. on pin 5. These make possible the use of a scintillation head or a CR tube. The 10 megohm resistor taking the EHT feed is safe enough to allow the GM anode to be held in the hand, though this is not encouraged, of course. Two chrome handles are used for carrying the instrument. Escutcheon plates marked with UNO guides are included. The bottom has rubber pads, and carries four 1 in. holes for ventilation. The circuit is arranged so that alternative valve types can be interchanged. The cost of the components is given in Table 1.

A simple suitable GM tube sensitive to alpha, beta and gamma rays such as the Mullard 18504 would cost an extra £5 4*s*. 5*d*. or so.

The amplifier section, at the bottom of the circuit diagram, contains the Ferguson power transformer PF545 with extended 1,000v HT winding designed for oscilloscopes, and three rectifiers to provide separate d.c. voltages. For the EHT supply there is the 2X2 valve, a half-wave rectifier, providing a low current drain of 100 microamps, at over 1,200v. A 220 kW resistor and 0.1 microfd capacitor supply filtered d.c. at 1,200v, applied to a potential divider resistor chain attached to a single bank 11-position OAK switch. Consistent ratios are more important than exact values. The EHT tapped from the divider is fed to the octal socket and to the GM socket through a 10 megohm resistor.

In the 400v line, full wave rectification is by means of a 6X5 rectifier and capacitor-inductance filtering, supplying just over 400v at the current drain. This supplies anode potential to all tubes in the amplifier and display sections, and to the octal socket. In the −15v bias line, there has to be sufficient negative potential in the control grid to render the driving amplifier non-conducting except on pulse arrival. The voltage is supplied by voltage doubling the heater supply using a 6H6 valve.



Holder for Philips GM Tube 18504 (aluminium)

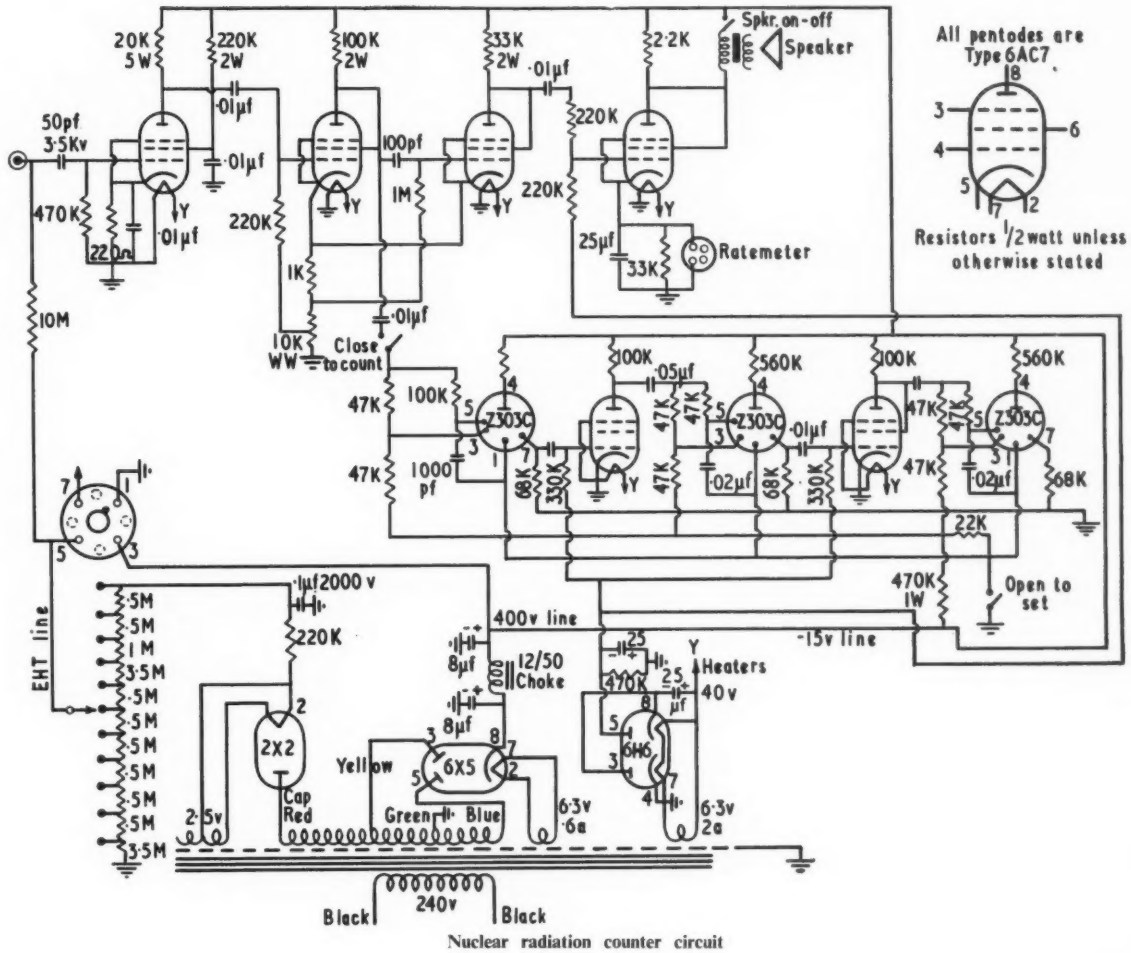
Table 1. Cost of materials

		£	s.	d.
Industrial case	13×8×6⅞ in. R.H. Oxford type MC82A	2	0	0
Handles	2		5	4
Chassis	2 sq.ft 16-gauge aluminium		8	6
Transformer	Ferguson PF 545	3	15	0
Choke	12/50		10	6
Speaker	3 in.	1	0	9
Speaker transformer	10,000 ohm		10	9
Valves	6×6AC7 (or 6SH7, or EF50 with base change)		15	0
	1×2X2 (or AV11, mounted through chassis)		5	0
	1×6X5 (or 6X4, with base change)		10	0
	1×6H6		2	6
Dekatrons	3×Z303C Mullard or GC10B Ericcson	6	12	0
Valve sockets	12 octal, 1 four-pin	1	0	4
Switches	1×11 position OAK		8	1
	1 toggle		6	3
	1 three-position (disposals)		2	6
Plugs and sockets	1 Belling-Lee ½ in. coaxial for GM		1	10
	1×4-pin miniature speaker type (ratemeter)		1	5
3 yd 3-core power flex and 3-pin plugs			5	9
Condensers	Electrolytic 2×8 microfd 600v filter		7	10
	3×25 microfd 40v		7	6
	High voltage 1×50 pf, 3.5 kV		3	4
	1×0.1 microfd 2,000v		3	6
	Others 2×0.05 microfd		2	2
	2×0.02 microfd		1	8
	6×0.01 microfd		7	6
	1×100 pfd			10
	1×100 microfd			10
Resistors	1×20K, 5w		3	0
	3×2w carbon 10 per cent. tol.		4	6
	1×1w carbon 10 per cent. tol.			8
	32×½w carbon 10 per cent. tol.		16	0
	11×½w carbon 3 per cent. tol. (EHT pot. divider)		9	2
Potentiometer	10 kW		9	6
Miscellaneous	Hook-up wires, tag strips, nuts, bolts, solder, rubber feet, etc.		15	0
		£23	14	6

Now in the amplifier section we find the four valves shown at the top of the circuit diagram. The 6AC7 was chosen as a stable, high gain pentode, with a robust metallic envelope. Valve 1 amplifies the negative input pulse from the GM, a positive pulse appearing at the plate of this valve, and the amplified pulse having the same shape as the input pulse, with sharp rise and exponential decay.

Valves 2 and 3 operate as a flip-flop circuit, generating a square pulse, the size of which is independent of the size of the applied output pulse which triggers it. This provides positive action on the scaler, the ratemeter including tracks linearly with respect to count-rate. For economy and uniformity of valve types, this circuit uses two separate pentodes connected through a triode, each pentode conducting when the other does not. A positive pulse from the first valve triggers the circuit, providing a negative square pulse from the first of the two flip-flop valves used to drive the first Dekatron. The square positive pulse from the second valve drives the speaker and ratemeter. The fourth valve, driven by positive pulses from the flip-flop circuit, operates the speaker and ratemeter. The latter can be a moving-coil meter requiring 1 ma or less for full deflection, sensitivity being adjusted by means of a series resistor if required.

Now we come to the scaling section, with its Dekatrons. Base pin 4 of the Dekatron tube socket is the anode, pin 7 is the "0" position cathode, pin 1 is connected to the



Nuclear radiation counter circuit

remaining numbered positions, pin 3 to the first guides, and pin 5 to the second guides. A negative pulse from the triode-connected 6AC7 driving tube appears at once on the first guides, then on the second guides. When the discharge has gone around to the "0" position, a pulse is transferred via the 0.01 microfd condenser to the next 6AC7 driver. For resetting, earth connections to all cathodes except to "0" are broken.

The first constructional step is to mark out, cut, and bend the chassis. The $\frac{1}{8}$ in. mounting holes are inserted as required. All components except the valves are mounted before wiring, the choke being mounted before the power transformer which is above it. Pins No. 6 of the Dekatron sockets are uppermost, so that the "0" positions are at the top. Holes for these sockets should be slightly oversize. The 10,000 ohm potentiometer in the flip-flop goes through the $\frac{7}{8}$ in. hole in the main chassis just in front of the sub-chassis. A slot cut in the end of the shaft enables adjustments to be made with a screwdriver. Main- and sub-chassis should be wired separately, the two being assembled later, and leads taken to mutual tag strips under the main chassis. All heater and earth connections are made first. Unused pins 2, 6 and 8 of the Dekatron units can be used as wiring lugs for mounting the components, with a tap strip between Dekatron and 6AC7 sockets. When the sub-chassis has been attached and the circuit checked, the valves are plugged in and the counter tested. The potentiometer in the flip-flop cathode which is mounted through the main chassis in front of the sub-chassis is adjusted with a screwdriver, an optimum setting being midway between the position at which sensitivity is too great and that at which the flip-flop is sensitive enough to go into oscillation.

No. 52 Photographic demonstration of thorium decay

F. R. Paulsen, U.K.

A strip of Ilford G5 nuclear emulsion research plate, about 1 × 3 in., is soaked for 10-15 min in a 1 per cent. solution of thorium nitrate. It is then rinsed and dried and left for several days in the dark. The plate is developed, fixed, washed and dried, and examined under a microscope with a $\frac{1}{6}$ in. objective and x10 (or better, x15) eyepiece. The "stars" visible on the plate are evidence of radioactive decay of the radiothorium and its daughter products, the alpha particles from which leave tracks in the emulsion. The tracks may be reproduced in the form of photomicrographs.

No. 53 The dynamic nature of the iodide ion

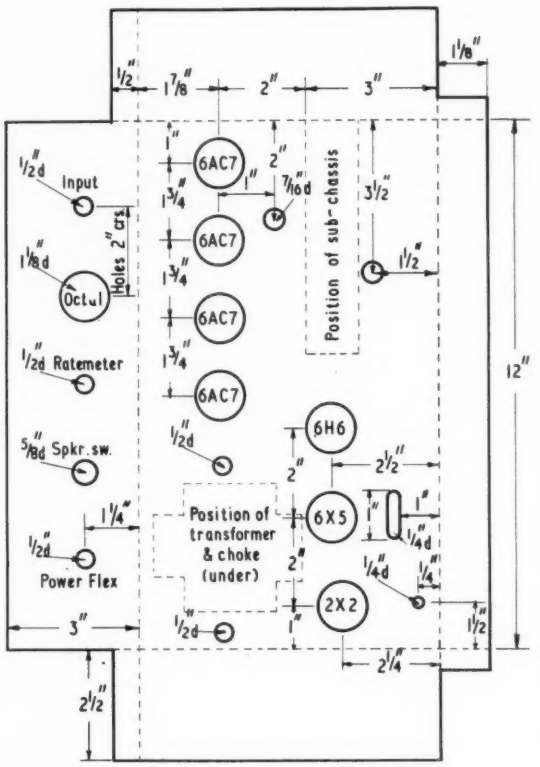
Richard F. Blake, U.S.A.

A reaction which can be used to demonstrate the dynamic nature of ions is:

$$\underset{\text{solid}}{AgI\text{-}127} + \underset{\text{solution}}{(I131)^-} \longrightarrow \underset{\text{solid}}{AgI\text{-}131} + \underset{\text{solution}}{(I\text{-}127)^-}$$

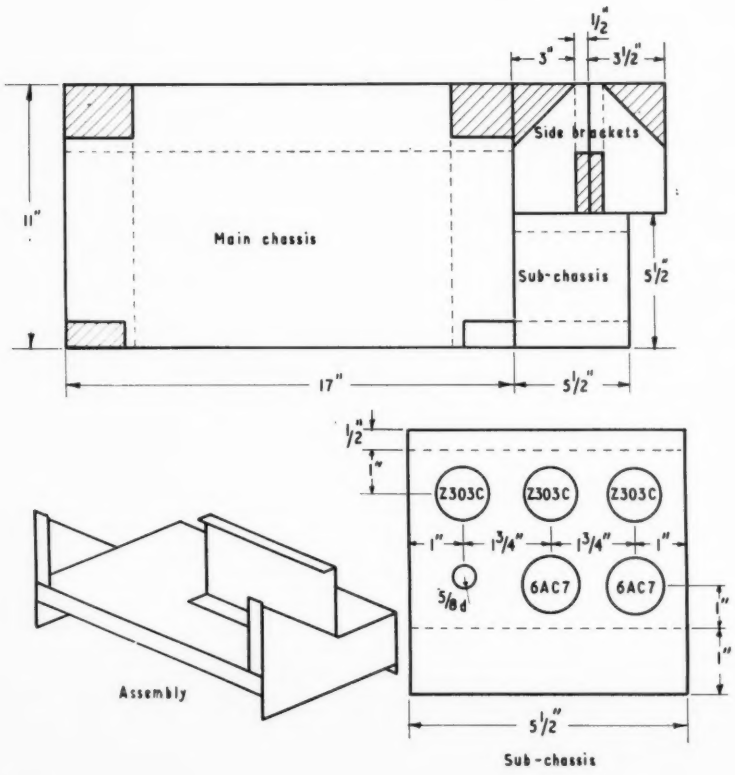
This reaction is selected as the I131 is readily obtainable, and the low solubility of AgI makes it virtually insoluble, with a solubility constant of only 1.0×10^{-16}.

10μc of NaI-131 are diluted with water to 30 ml, and divided evenly between three small test tubes. (The original solution contained 10 μc in 10 ml of carrier-free 5.2×10^{-7}M NaI solution.) The three lots of solution are tested with a radiation counter to see that they are equal in activity. Tube 1 is used as control, to show the $t\frac{1}{2}$ for I-131. To tubes 2 and 3 are added 200 mg of fresh inactive AgI. Tube 2 is shaken thoroughly between each reading,

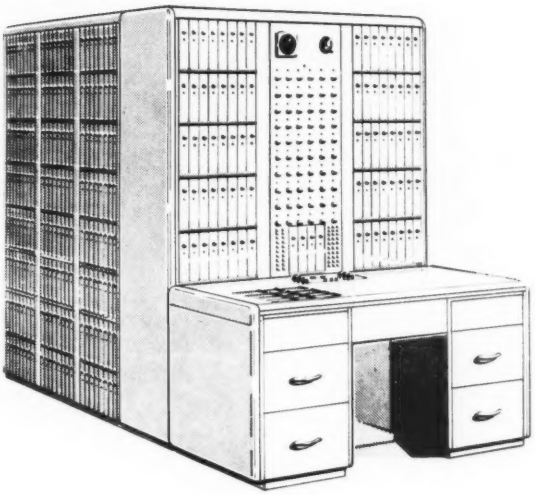


Main chassis (material; 16-18 A1)

Chassis components for the nuclear radiation counter



while tube 3 is handled with care to prevent agitation, to show the difference in ion exchange rate by mixing. Readings are taken at top, middle and bottom of each tube at 15 min intervals for a period of two hours. A shield can be made so that only that special part of the tube selected will be tested for radioactivity. This may be in the form of a piece of lead foil $\frac{1}{8}$ in. thick, surrounding the tube, and with a 1×3 cm window cut in it. Background readings should be subtracted in all cases. The counting assembly must always retain the same geometry. After initial readings, tube 2 is shaken well for 5 min and the AgI allowed to settle while the other tubes are counted. This procedure is followed each time, with constant intervals between readings on all tubes. Readings on tube 1 decrease exponentially with a $t\frac{1}{2}$ of 8 days. In tubes 2 and 3 the count at the bottom rises as the (I-131)′ exchanges with AgI in the solid, and readings at centre and top of tubes fall as the (I131) is removed from the solution. There will be evidence of ion exchange in as little as a couple of hours. The shaken tube exchanges more rapidly than the unshaken one. △△△



New Reactor Simulator by Shorts

OPERATORS can be fully trained on this new reactor simulator by Shorts, which has been ordered by the UKAEA for installation at its Calder Operations School. The simulator will enable an operator to attain a very high degree of proficiency in reactor control, including dealing with such emergencies as the development of instability in the pile. The behaviour of a complete nuclear power station can be reproduced by the large special purpose analogue computer developed by Shorts for this simulator and containing 200 computing amplifiers.

For simulation purposes a reactor is split into three zones in this system. Each zone has one nucleonic and one core heat transfer simulation unit which are mounted together in a standard Post Office type rack about 7 ft high. It is therefore a simple matter to provide duplicate units for splitting the reactor into smaller zones. In all, the simulator consists of five racks and a console. The fourth and fifth racks house equipment for reproducing the behaviour of heat exchangers, steam production and flow, and the generator section. Information will be supplied on fuel cartridge radiation, inlet and outlet temperatures of the gas, steam pressures and rate of flow, position of the control rods, turbine speeds and electrical power output.

A special mock reactor control desk is being designed by the UKAEA Research and Development Branch for use with the simulator to be installed at the Calder Operations School. Instruments on this desk will be controlled by the simulator, which will also interpret control adjustments made by the operator. Signals to the control desk will then be modified accordingly.

In this way, as far as the operator is concerned he is to all intents and purposes controlling a power station. One of the features of this simulator is that it can reproduce undesirable conditions with their results, and remedies can be demonstrated as many times as required. Variations in demand for electric current and failures in steam production from one of the heat exchangers are among the conditions which can be reproduced.

Simlac Units

Much of the equipment developed for the new Short Simlac multi-unit computer have been incorporated and overall component error will be less than one part in one thousand. The power units are fully transistorized and the system has been so designed that additions can be made without disturbing the original equipment. Only small modifications will be needed to convert from simulation of the Calder Hall type reactor to the advanced gas-cooled type. △△△

MONOGRAPHS RECEIVED

A Report on the First Loading of ZENITH. Published by Industrial Power Reactors Division, AEE, Winfrith. Reference AEEW-R50. Available from HM Stationery Office. Price 11*s*.

Lectures on Criticality. Published by Health and Safety Branch, UKAEA, Risley. Reference AHSB(S) R4. Available from HM Stationery Office. Price 9*s*.

Very Small Probes for Flow Measurement, by R. Ramshorn. Translated from V DI Zeitschrift by R. Presser. Published by Development and Engineering Group, UKAEA, Risley. Reference DEG Information Series 57 (CA).

The Treatment of Thermal Scattering Law Data, by P. A. Egelstaff. Published by Nuclear Physics Division, AERE, Harwell. Reference AERE-R3622. Available from HM Stationery Office. Price 5*s*.

A Magnetic Tape Recording System for Nuclear Physics Research, by I. N. Hooton. Published by Electronics Division, AERE, Harwell. Reference AERE-R3422. Available from HM Stationery Office. Price 7*s*.

An Automatic 1,000 Channel Read-out System, by R. L. Elliott. Published by Electronics Division, AERE, Harwell. Reference AERE-R3291. Available from HM Stationery Office. Price 4*s*. 6*d*.

Measurement of the Specific Heats of Santowax 'R,' Parameta- and Ortho-terphenyl, Diphenyl and Dowtherm 'A' by R. W. Bowring, D. A. Garton and H. F. Norris. Published by Reactor Development Division, AEE, Winfrith. Reference AEEW-R38. Available from HM Stationery Office. Price 7*s*.

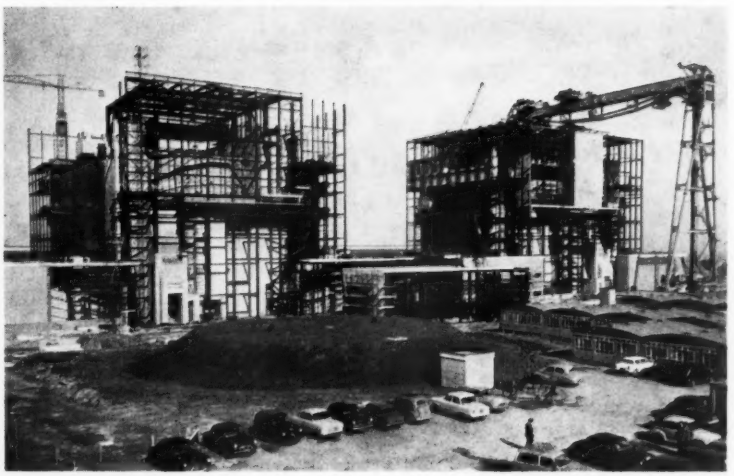
The Measurement of the Scattering Law for a Moderator, by P. A. Egelstaff. Published by Nuclear Physics Division, AERE, Harwell. Reference AERE-R3593. Available from HM Stationery Office. Price 2*s*. 6*d*. △△△

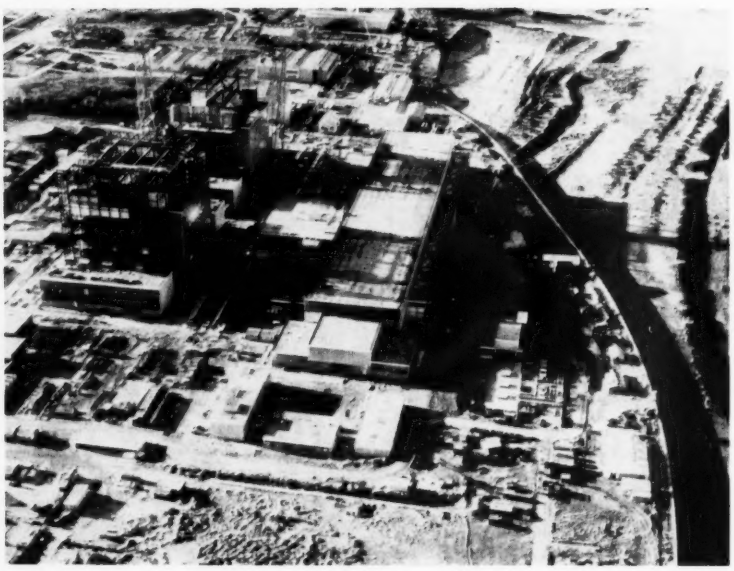
POWER STATION REVIEW

Hinkley Point

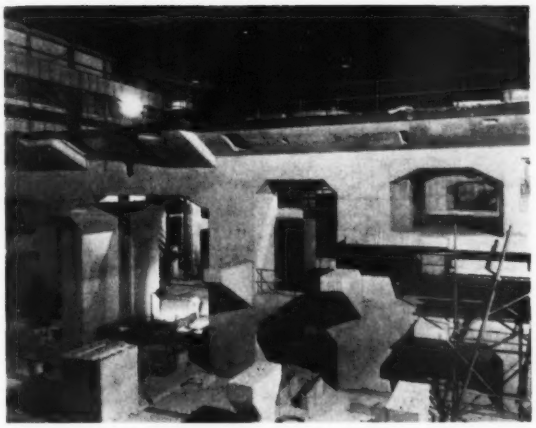
(Right) *Control recording room during the pressurization test on No. 1 reactor pressure vessel at Hinkley Point nuclear power station*

(Right) *View of Hinkley Point showing the Goliath crane and the two reactor buildings, No. 2 is on the left. The six steam rising units for both the reactors are now in position and work is almost complete on the insertion of the studded elements under scrupulously clean conditions. Both reactor pressure vessels have been fully installed and No. 1 has been stress relieved and pneumatically pressure tested in preparation for the laying of the graphite core. Installation of condensers for the turbo-alternator sets in the turbine hall is approaching completion and No. 1 alternator stator is in position*

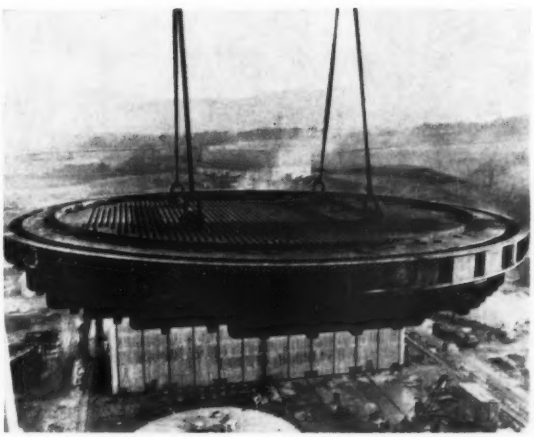




All 12 heat exchangers have now been installed at Hinkley Point and pile cap roofs of both reactor buildings are nearly complete. The aerial view (left) *shows the two reactors and the Goliath crane. On the right is the 700 ft long turbine hall. The giant 67 ft diameter pressure vessel for No. 1 reactor has been tested on site to a pressure of 310 lb/sq.in. which is over 1½ times the pressure it will have to withstand under service conditions. More than 3¾m. cu.ft of free air were pumped into the vessel to achieve this pressure. Moisture was first removed from the air by special driers. A vacuum test was also carried out on the vessel. Stress and temperature readings were obtained through 274 strain gauges and thermocouples fixed inside and outside the vessel and joined together by 20 miles of special cored wire*

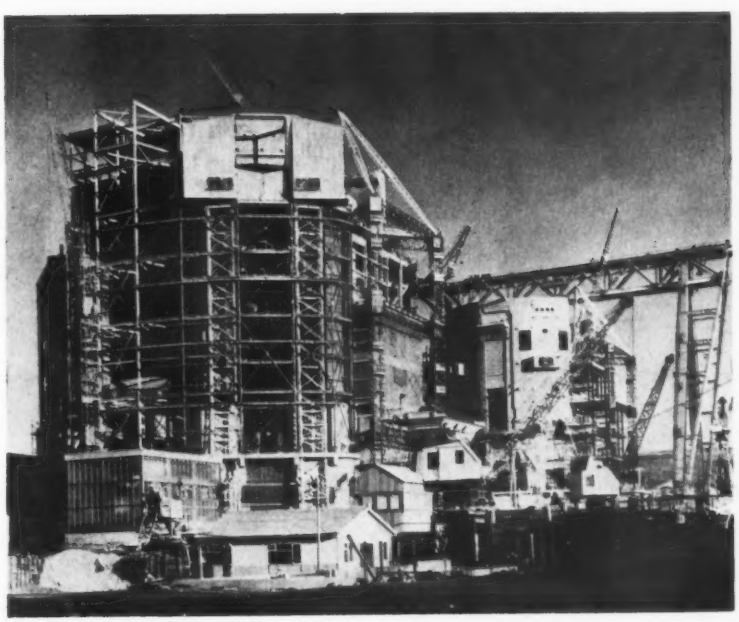


The turbine hall at Hinkley Point. This picture shows the massive concrete plinths for supporting the turbo-alternator sets. Equipment is being installed at a high rate, the main turbine and dump condensers, and the first alternator stator are in position. Two generator transformers are installed in bays adjoining the turbine hall walls. Hinkley Point is the first 500 MW atomic power station to be built in the world. The station is being built for the CEGB by the English Electric, Babcock & Wilcox, Taylor Woodrow Atomic Power Group. This group has recently started work on the 580 MW station at Sizewell. The first reactor at Hinkley Point will go into service next year



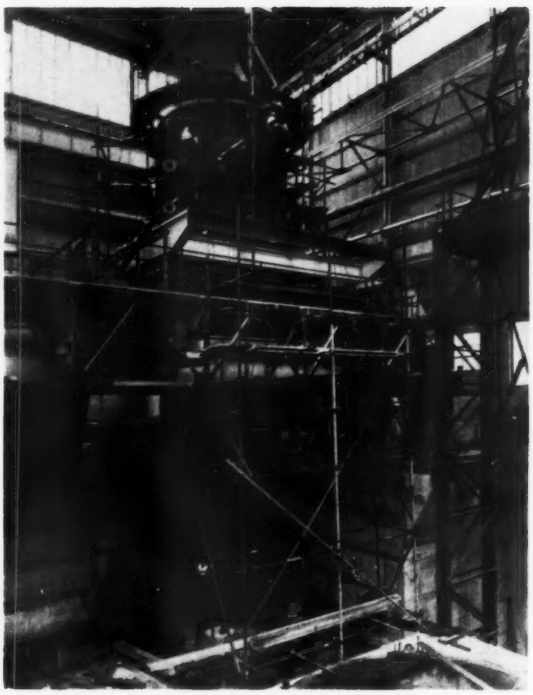
Hunterston

(Left) *The 340 ton core-support for reactor B at Hunterston being lowered into position inside the pressure vessel. This station is being built for the South of Scotland Electricity Board by the General Electric Company and Simon-Carves Atomic Energy Group*



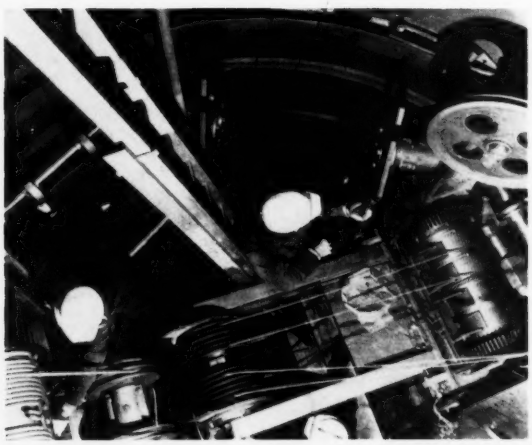
View of both the reactor buildings at Hunterston. Steam raising units are now in position in reactor A and installation of plant is in hand. Special buildings are erected on top of the shells to ensure the necessary clean conditions. With these shells in position work is continuing on the installation of the gas circulators and tubing. The pressure vessel for reactor A has recently been stress-relieved and the bottom head is being externally lagged with 6 in. thick thermal insulation. In reactor B fabrication of the pressure vessel is in process

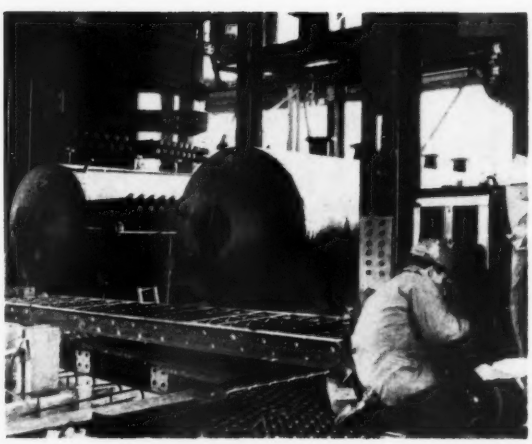
Installation of one of the main hot gas valves for controlling the flow of carbon dioxide gas between reactor A and its steam raising units. The hot and cold gas ducting, main valves and expansion bellows which link the pressure vessel with the steam raising units are being joined up



(Above) *The first Hunterston service machine which is at present being assembled at the Erith Works of The General Electic Company, Ltd. On-load routine maintenance of the reactor control rod assemblies will be the main use of this machine. Six special mechanisms are to be installed, the driving motors for two of them can be seen mounted near the top of the 41 ft high vessel. Only one mechanism can be used at one time due to built in interlocks. Maximum internal diameter is 11 ft and the machine, mechanisms carriage and 52 ft span bridge will together weigh 180 tons*

(Below) *The first service machine viewed from the top. On the left the control rod recovery mechanism can be seen in the stowed position; on the right is the control rod assembly handling mechanism in one of the two operating positions. The other operating position has to be selected for removing the standpipe cap and its mechanism. A complete assembly consists of a hoist motor, standpipe cap, concrete plug, control-rod rope and control rod.*





(Right) *Steam drums located between two of the steam raising units for the first reactor. In all there are five steam raising units for this reactor and most of the structural steelwork near them has now been completed. This face of the reactor is almost ready for glazing. Final cleaning and assembly of the gas circulators is at present being carried out at The General Electric Company's Erith Works. Eight gas circulators will be used to circulate coolant through each reactor. Reactor A is scheduled to go critical in August, 1962 and reactor B in May, 1963*

△△△

NUCLEAR NOTES

Ghana mission

A PRELIMINARY assistance mission has been sent to Ghana. The five-man team is led by Mr. John Webb and is also visiting Dahomey, Liberia and Nigeria, who are not yet members of the IAEA. Current, planned and possible nuclear activities are being discussed with the respective national authorities.

Radioactivity of sea

THE Government of Monaco and the Oceanographic Institute in Monaco have concluded an agreement with the IAEA for research on the effects of radioactivity in the sea. Research will be directed towards the problem of possible pollution of the sea through the deposition of radioactive materials. Movement of water and marine organisms, the deposition of organic and inorganic matter, the distribution in marine organisms of radioactive materials already existing, and the effects on marine life of radioactive materials at various concentration levels will all be studied.

TRIGA for Yugoslavia

YUGOSLAVIA'S request to the IAEA for assistance in obtaining a TRIGA Mark II reactor to be installed at the Nuclear Institute "Jozef Stefan" at Ljubljana has been granted. The enriched uranium fuel will also be supplied through the IAEA.

IAEA Board enlarged

THE board of governors of the IAEA have recommended to the general conference that the board should in future consist of 25 instead of 23 members. The additional seats will be for member states from Africa and the Middle East.

Disposal techniques

AN international panel convened by the IAEA to consider a draft manual on low-level waste disposal techniques has started work. Special attention is being devoted to wastes resulting from the use of radio-isotopes.

Maritime Law

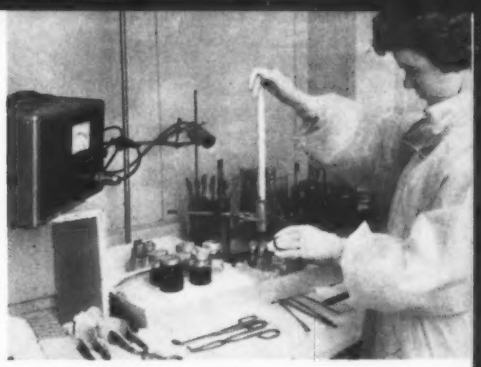
THE IAEA is taking part in the Diplomatic Conference on Maritime Law convened by the Belgian Government. Two working papers have been prepared by the Agency on "Liability of Operators of Nuclear Ships" and "Draft Conventions on Liability of Operators of Nuclear Ships." In addition to this, experts from the Agency's staff have been sent to the conference to advise on technical, scientific and legal points.

Radiobiologists meet

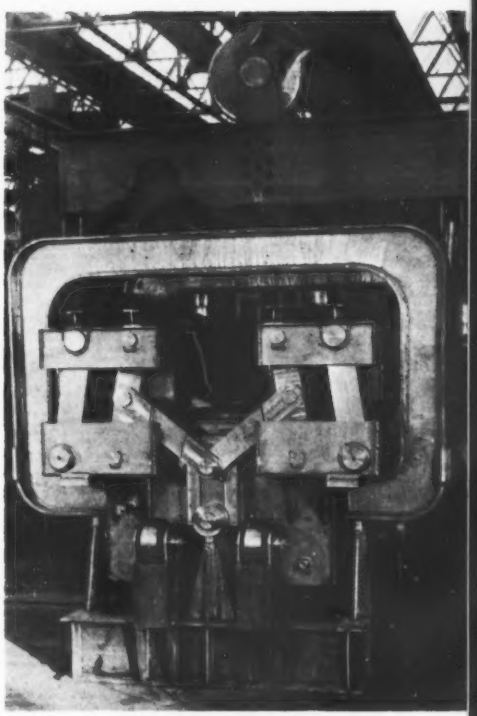
THE mechanism by which radiation damages the cell was one of the subjects discussed recently at a meeting of radiobiologists organized by the IAEA in Vienna. Methods were also discussed for using the results of radiobiological research in food preservation. It appears that food sterilization by a combination of heat and low-level radiation is most promising. A new technique suggested at the meeting is the irradiation of the cells of experimental animals to make them accept human viruses so that the growth, behaviour and control of the viruses can be effectively studied.

Hazards standards

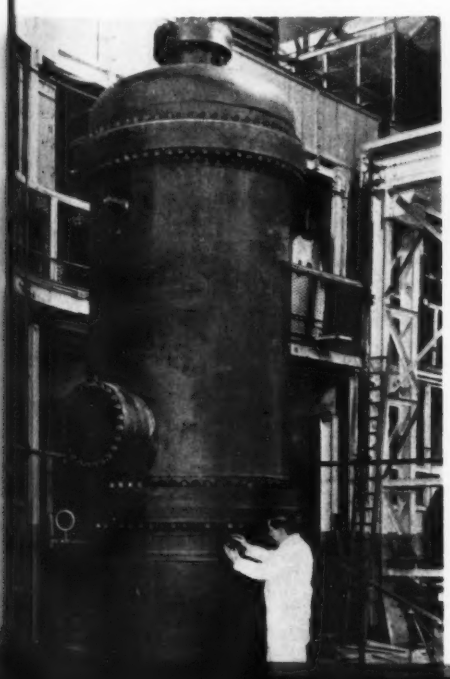
A 14-MEMBER intergovernmental committee recently considered the IAEA's draft international convention on minimum international standards regarding civil liability for nuclear hazards arising from land-based nuclear installations and in connection with the transportation of nuclear materials.



(*Above*) **Radioactive grease sample being unpacked from an isotope can for examination at the main research establishment of the Castrol group at Hayes. This sample has undergone irradiation in an atomic pile**



(*Above*) **"Hot" fuel elements at Berkeley will be transported to the cooling pond by this equipment built by Fairey Engineering at Stockport. It is made of stainless steel and consists of a "flask" mounted on a "cradle"**



(*Left*) **Class 1 pressure vessel erected at Fairey Engineering's Heston works for functional tests on mechanical equipment to be used in the Trawsfynydd nuclear power station reactors. The vessel, which is shown during an hydraulic pressure test, is 18 ft high and weighs 9·2 tons. Tests will be made inside it in an atmosphere of carbon dioxide at a temperature of 400° C. and at a pressure of 290 lb/sq.in., *i.e.*, under conditions similar to those in a reactor**

(*Right*) **Soon to be used at Trawsfynydd will be this new type restraint mechanism for accommodating thermal expansion in high pressure and high temperature piping systems. Developed by Richardsons Westgarth & Co., Ltd., its first use will be with conventional bellows convolution on the coolant gas ducting. The mechanism works on principles of elastic deformation, and consists of a large number of high tensile bars, grouped in two frusto-conical assemblies round the periphery of the duct. This arrangement makes the device equally flexible in any direction, the deformation being accomplished by transverse bending of the bars. In the axial direction it behaves as a stiff connection**

NUCLEAR NOTES

Electronics conference

NUCLEAR Electronics was the title of an IAEA conference held last month in Belgrade. A scientific exhibition was organized on the Belgrade Fair grounds in conjunction with the conference. The conference concentrated on electronic devices for the detection and measurement of radiation, electronic circuitry and advanced electronic systems used in nuclear research and applications.

Atomic insurance

THE British Insurance (Atomic Energy) Committee recently held a conference in London which was attended by representatives of countries interested in the insurance of atomic energy risks. This is the fourth such conference and follows meetings in 1957, 1958 and 1959, during which considerable progress was made towards finding solutions to common problems in this field. National legislation and international conventions played a large part in the conference this year.

Nuclear chair

GLASGOW University is to have a nuclear engineering department in the next three years or so. An Order in Council has been issued by the Queen approving an Ordinance providing for a Nuclear Engineering Chair. The University Court will make arrangements for the new department when financial and other considerations are favourable.

New nuclear company

NUCLEAR Developments, Ltd., is the title of a new company which has been formed by Imperial Chemical Industries, Ltd., Rolls Royce, Ltd., and The Rio Tinto Co., Ltd. The new company will operate in the field of civil nuclear engineering in collaboration with the atomic power consortia. The combined resources of the parent companies will be at the disposal of the new company.

Pakistan station

RECOMMENDATIONS on the type, size and locations of nuclear power generation plants to be built in Pakistan are to be made by the Internuclear Co. of Missouri and Gibbs & Hill, Inc., of New York. Cost comparisons are to be made between nuclear, thermal and hydro-electric power sources.

Accelerators

RESPONSIBILITY for the development of particle accelerators has been transferred to the Rutherford Laboratory of the National Institute for Research in Nuclear Science. Previously accelerators have been developed by the Accelerator Division, AERE, Harwell, and most of the staff concerned with this work have been transferred to the Rutherford Laboratory.

Halden charged

THE first charge experimental operation of the Halden boiling heavy water reactor has been successfully completed. During the experimental period with the first fuel charge the reactor was operated at powers up to 6,000 kW with temperatures up to 155°C., corresponding to the designed operating conditions for the first fuel charge. Later this year the reactor will undergo changes to accommodate the second fuel charge, increase output and expand the experimental facilities. During this period the reactor will be out of operation.

Fusion contract

EURATOM has concluded a contract with the Plasma Physics Institute (Max-Planck-Gesellschaft) of Garcging near Munich for research into controlled thermonuclear fusion. The contract is initially for three years and will cost a total of DM30m., 33 per cent. of which will be borne by Euratom and 67 per cent. by the Institute. Work in this field is already in hand in France and Italy under the auspices of Euratom and a further contract is in the process of negotiation with the Nuclear Research Centre at Juelich, Germany.

European ship

JOINT European action in the field of nuclear ship propulsion was the subject of a meeting of the ENEA's study group on ship propulsion which met recently in Paris. Two technical working parties were set up to examine (*a*) the economic potentialities of nuclear ship propulsion and the various reactor types at present under construction or envisaged, and (*b*) the means by which a European joint undertaking could be set up for construction and operation of a nuclear ship.

ISPRA transferred

ISPRA research centre has now been formally handed over to Euratom by the Italian Government. Euratom now has its first large-scale general research centre. At present 800 people work at Ispra; by the end of 1962 the staff will number 1,500.

ENEA seminars

TWO international seminars on nuclear energy have been organized by the ENEA at Harwell and Saclay. They are intended for university teaching staffs and will study the latest advances in nuclear science and techniques. A certain amount of practical work and visits to nuclear installations will be included. The Harwell seminar will take place from July 10th to 21st and that at Saclay from June 26th to July 7th. All costs apart from travelling expenses will be borne by the ENEA.

TRIGA power

TRIGA research reactors are now available from General Dynamics with a higher power rating of 250 kW for steady state operation, providing a flux of 10^{13}n/sq.cm/sec. This means expanded facilities for research training and testing, as well as the production of isotopes.

BEPO Wigner release

THE BEPO reactor at Harwell has recently undergone a successful Wigner energy release. This was carried out by externally heating the air stream normally used to cool the reactor. Heated air was passed through the reactor for 22 hours at about 9 per cent. of the normal operation flow rate. The reactor was run at a very low power level, about 50 kW, so that the burst cartridge detection equipment could be used.

Waste storage method

RECENT work by the UKAEA Chemical Engineering Division has shown that it may be possible to store radioactive wastes by converting them into insoluble glass-like solids. This is done by making a slurry of silica and borax in a nitric acid solution of the concentrated wastes, which is then evaporated to red heat, whereupon it sinters and melts. On cooling the solution solidifies into a glass of chosen composition. It might, for instance, contain from 20 to 30 per cent. by weight of waste oxides. Properties of the glass remain practically unchanged when samples are subjected to a radiation dose of 10^{11} rads. This is equivalent to glass containing high activity waste which has been stored for 500 years. The design of a pilot plant for handling 1,000 curies of radioactive waste per batch is now in an advanced stage.

Uranium in Scotland

INVESTIGATIONS into uranium occurrences on the Solway coast in south-west Scotland have confirmed the existence of sporadic uranium over a distance of two miles, parallel to the coast and extending to a depth of some 200 ft. The work has now been completed and no further work is at present contemplated.

Australian co-operation

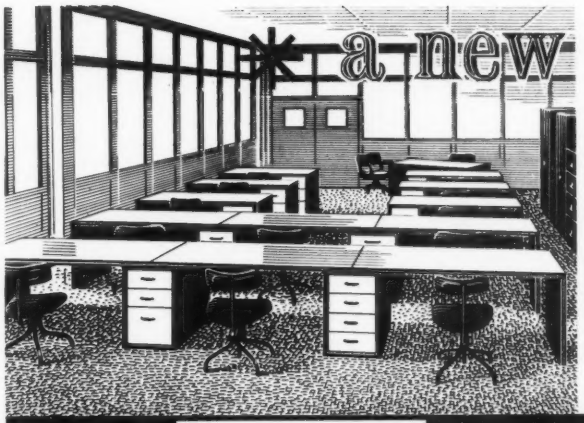
RESEARCH co-operation was the subject of recent discussions between a three-man mission from the UKAEA and the Australian Atomic Energy Commission in Sydney.

Observations please

THE Ministry of Labour has published a preliminary draft with the title "Unsealed Radioactive Substances Regulations" on requirements for the protection of persons employed in factories against ionizing radiations and other hazards arising from the use of unsealed radioactive substances. The draft is available from HM Stationery Office, price 1*s.* 3*d.*, and any observations on it should reach the Ministry of Labour by July 31st, 1961.

New films

A NUMBER of new films are now available from the Central Film Library; their titles and running times are as follow: The Dounreay Fast Reactor, 37 min.; The Dounreay Project, 23 min.; Chapelcross, 20 min.; Operating a Calder Hall Reactor—Refuelling, 31 min.; Operating a Calder Hall Reactor—Full Power, 20 min. All these films are available on free loan and the last three are in colour.



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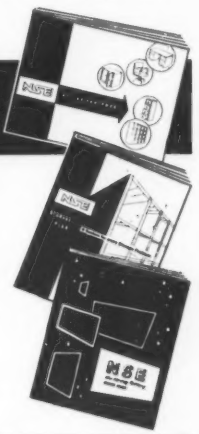

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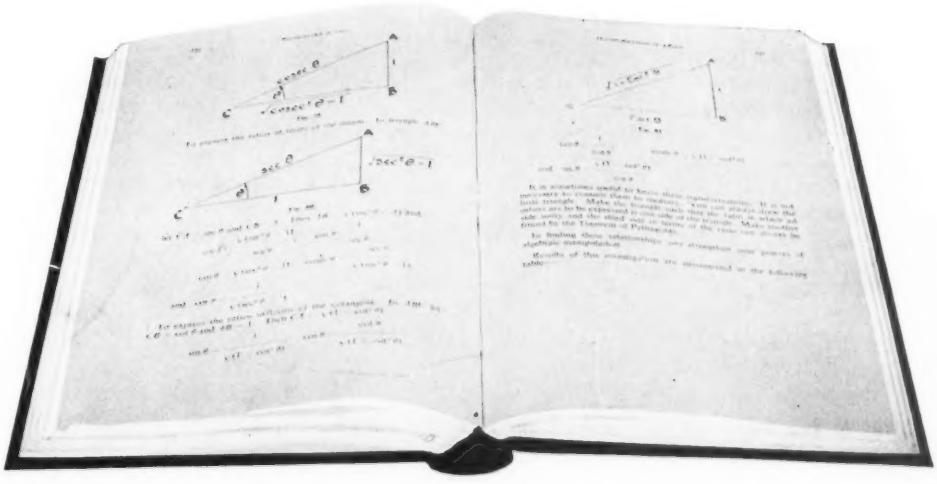

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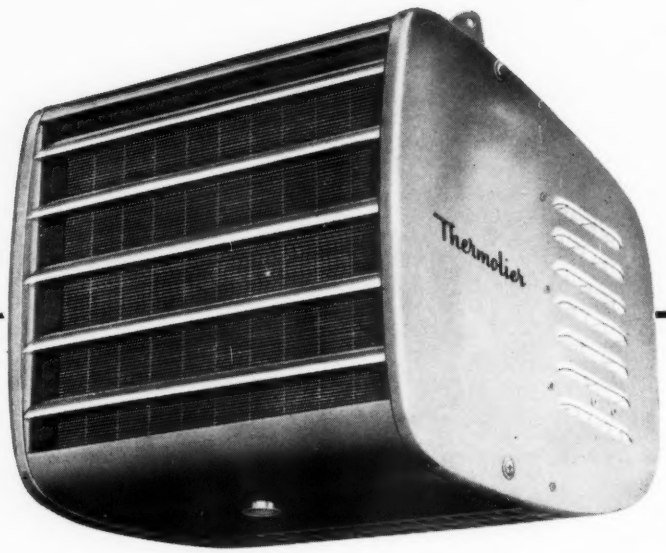

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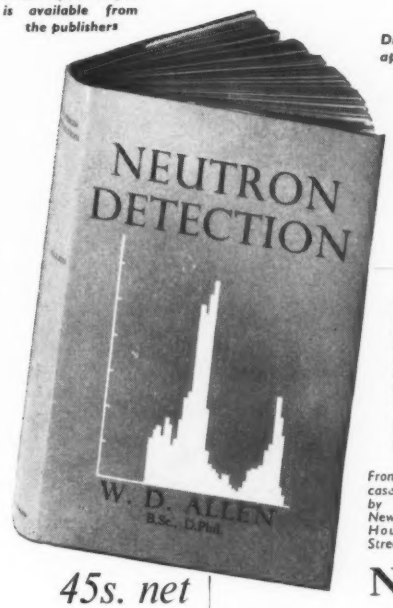

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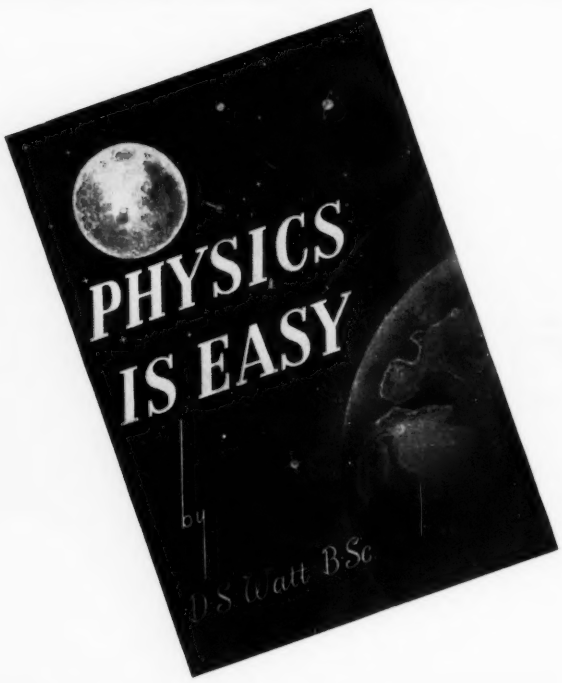

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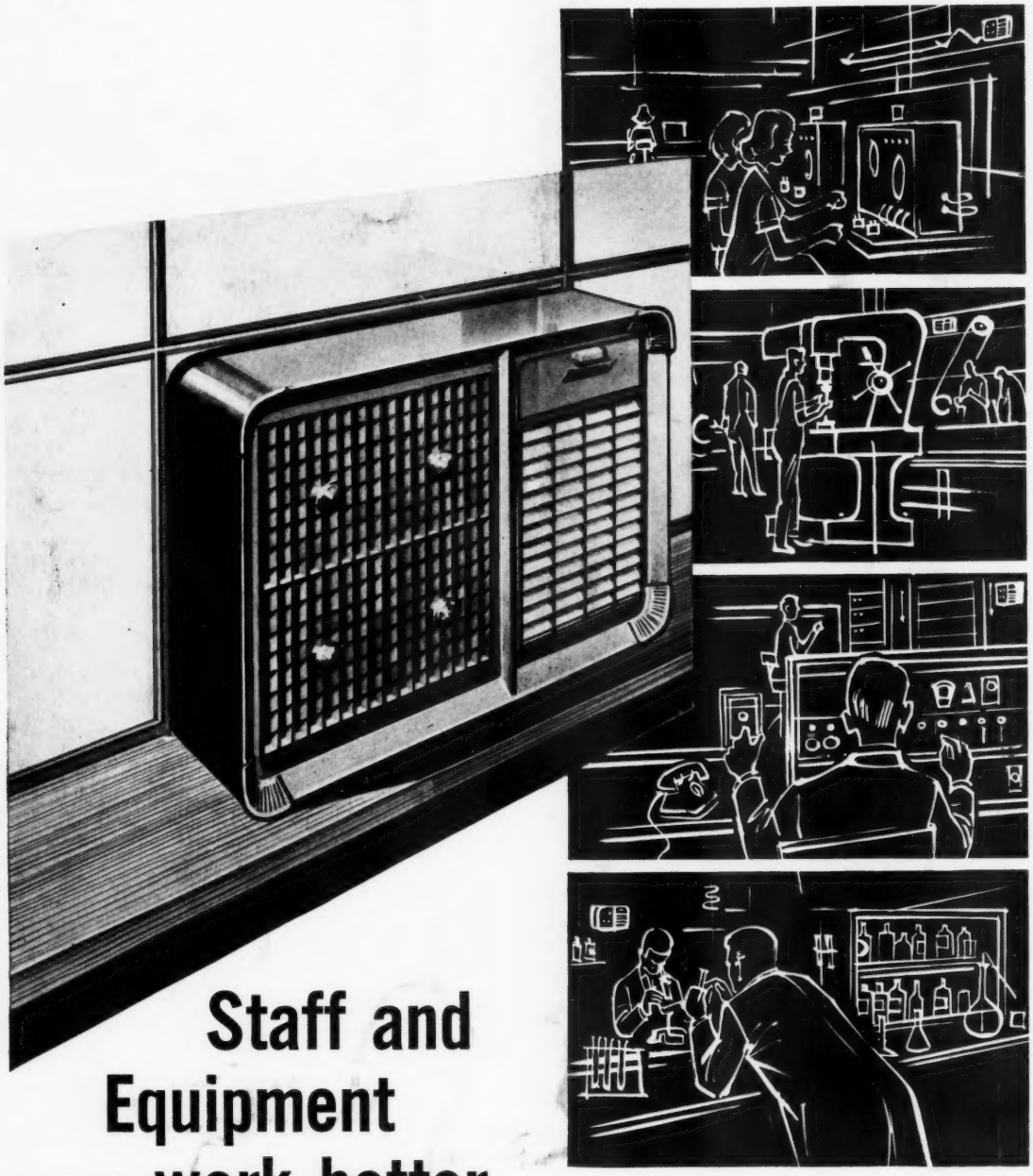

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